Region-Based Fractional Wavelet Transform Using Post Processing Artifact Reduction

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Abstract

Wavelet-based algorithms are increasingly used in the source coding of remote sensing, satellite and other geospatial imagery. At the same time, wavelet-based coding applications are also increased in robust communication and network transmission of images. Although wireless multimedia sensors are widely used to deliver multimedia content due to the availability of inexpensive CMOS cameras, their computational and memory resources are still typically very limited. It is known that allowing a low-cost camera sensor node with limited RAM size to perform a multi-level wavelet transform, will in return limit the size of the acquired image. Recently, fractional wavelet filter technique became an interesting solution to reduce communication energy and wireless bandwidth, for resource-constrained devices (e.g. digital cameras). The reduction in the required memory in these fractional wavelet transforms is achieved at the expense of the image quality. In this paper, an adaptive fractional artifacts reduction approach is proposed for efficient filtering operations according to the desired compromise between the effectiveness of artifact reduction and algorithm simplicity using some local image features to reduce boundaries artifacts caused by fractional wavelet. Applying such technique on different types of images with different sizes using CDF 9/7 wavelet filters results in a good performance.

Keywords: 2D-DWT, Fractional wavelet, CDF 9/7, VSNs, Blocking artifact.

التحويل المويجي الكسوري بإستخدام المعالجة البعدية لتقليل آثار الحدود وإعتماد المناطقية

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الملخص

إستخدمت الخوارزميات المعتمدة على التحويل المويجي بشكل كبير في عملية الترميز في تطبيقات التحسس النائي عبر الأقمار الصطناعية، ومعالجة الصور الجغرافية، بالإضافة إلى ذلك أصبحت تطبيقات الترميز المعتمدة على التحويل المويجي، تستخدم بشكل كبير في مجال الاتصالات ونقل الصور عبر شبكات الاتصالات. بالرغم من أن متحسسات الوسائط المتعددة اللاسلكية أصبحت تستخدم بشكل واسع لنقل مكونات الوسائط المتعددة وذلك لتوفر كاميرات (CMOS) الرخيصة الثمن، الا أن هذه الأجهزة لها ذاكرة وقدرات معالجة محدودة. من المعلوم استخدام التحويل المويجي في عقد متحسسات الكاميرات الرقمية التي تحوي ذاكرة بسعة قليلة، سيؤدي الى تقليل حجم الصورة الناتجة. أصبح استخدام التحويل المويجي ألكسوري مؤخرا من الحلول المفيدة لتقليل الطاقة اللازمة للعمليات الحسابية ومدى الترددات اللاسلكية للأجهزة ذات المصادر المحدودة مثل الكاميرات الرقمية. إن إستخدام التحويل المويجي الكسوري سيؤدي إلى تقليل الذاكرة المتطلبة للمعالجة ولكن سيكون ذلك على حساب جودة الصورة. في هذا البحث، اقترحت طريقة متكيفة لتقليل مشاكل التحويل المويجي الكسوري باستخدام عملية ترشيح كفوءة ،مع الاخذ بنظر الاعتبار التسوية بين الكفاءة والبساطة في عملية المعالجة وذلك باستغلال بعض الخواص المحلية للصورة لتقليل التأثير السلبي على الحدود الناتجة من عملية التحويل المويجي الكسوري. إن تطبيق الطريقة المقترحة على صور بمختلف الأحجام والأنواع وباستخدام مرشح التحويل المويجي 9/7 أدى إلى نتائج جيدة.

1. Introduction

Nowadays, digital media services are found in many applications, therefore the demand of good quality images is increasing rapidly, but it is known that a higher quality may require larger sizes of images. A problem can be faced when there is no enough device storage or when sending these images throw limited bandwidth networks or even using limited resources cameras in distributed system. These cameras are widely utilized for a variety of monitoring applications, such as security systems, video surveillance, object detection, environmental monitoring, Traffic avoidance, etc. [1]. These applications make use of camera modules capturing a flow of images; process them with minimum amount of computations and transfer image information or the image itself to the network server.

Low cost digital camera technology was emerged due to the production of cheap CMOS (Complementary Metal Oxide Semiconductor) camera sensors which can acquire rich media content from the environment like images and video [1]. Availability of low-cost CMOS cameras created the opportunity to build low cost Visual Sensor Networks (VSNs) platforms with the ability to capture, process, and disseminate visual data collectively [2]. Their design is still challenging due to the size of images captured by a camera. That because the computational and memory resources of low cost camera sensor are typically very limited, as the employed low-energy microcontrollers provide only hardware with limited operations and have very limited random access memory (RAM) size, processors power, and memory access speed. The problem of memory consumption may restrict many images processing application, therefore several well-known image compression schemes are developed to reduce image size. Such compressions will help in reducing data traffic in sensor networks.

Wavelet-based methods are valuable solutions in the cases where strict constrains on the construction is needed, since wavelets provide accurate and excellent enough tool to approximate the datasets and signals. This is possible because, most data sets have a correlated frequency and time (or spatial) domains [4]. Wavelet transform is one of the best image compression techniques, but it still consumes memory resources. Since memory use and execution time of the DWT computation grow linearly with the image size, even high-performance workstations with plenty of memory can find it difficult to deal with the wavelet transform of large-scale images [5]. One major difficulty in applying the discrete two-dimensional wavelet transform is the need for large memory. For limited memory devices this operation can create a problem for large size images, which may seriously affect memory-constrained devices.

Line-based algorithm was proposed to use lines in decoding, where the memory used for coefficients can be released and more lines can be read. In the next step, the order of the coefficients is rearranged with some extra buffers to allow efficient use of memory in both encoders [6]. A block-based implementation of the DWT was also used in order to match with block-based encoders and to reduce the memory usage of the wavelet transform [7]. A general recursive algorithm was proposed on PC computers in *Ref.* [5] to compute the DWT in a line-based fashion to reduce memory and cache sizes.

Recently, the fractional wavelet filter was presented by S. Rein and M. Reisslein [3]. Bio 9/7 Wavelet transforms is used on a low-memory digital sensor. They explain how to compute a fractional wavelet transform on a microcontroller; although fractional wavelet reduces memory size it has some artifacts on the fraction end boundary. Post processing region-based fractional wavelet transform is proposed in this paper where picture quality can be significantly improved by decreasing fractional artifacts.

In this paper, implementations of three wavelet algorithms (traditional, fractional and region-based) by means of a simple filter bank, using CDF 9/7 wavelet filter and adaptive solution for fractional artifact are presented. The rest of this paper is arranged as follows: Section 2 contains a brief review of discrete wavelet transform. In Section 3, fractional wavelet transform is presented, Section 4 describes fractional wavelet artifacts. An existing method for the reduction of blocking effect is also explained in this section. Section 5 presents the proposed post processing region-based fractional wavelet transform. In Section 6, some results and discussions are given. Finally, Section 7 concludes this paper.

2. Discrete Wavelet Transform

Discrete Wavelet Transform (DWT) can be viewed as a multi-resolution decomposition of a signal. In general to perform forward one-dimensional Discrete Wavelet Transform (1D-DWT) which is also called the (analysis) operation, the set of signal samples is simply passed through low-pass and high-pass filters by convolution operation. The output is then down-sampled by a factor of two. The down-sampled low-pass output represents a low-resolution version of the original set that contains its half resolution. Such down-sampled output will be used to construct the next level. On other hand, the down-sampled high-pass output represents a residual version of the original set that is needed for the perfect reconstruction (synthesis) of the original set [8]. The same process can be applied on two-dimensional arrays and is called two-dimensional Discrete Wavelet Transform (2D-DWT), since digital images can be treated as multi-row and multi-column 2D arrays. 2D-DWT can first be applied as a 1D-DWT on each row in the image as one-dimensional signal. After finishing processing all rows, another 1D-DWT is then applied to each column of the result of the previous process [9]. 2D-DWT is illustrated in Figure 1 for both analysis and synthesis structures with L and H as Low pass and High pass decomposing filters, respectively, L' and H' as Low pass and High pass reconstructing filters, respectively, I as the original image and I' as the reconstructed image. In this paper, the CDF 9/7 wavelet filter which is selected as inclusion in the JPEG2000 standard [10] is examined. In the following subsections, explanations of this filter are given.

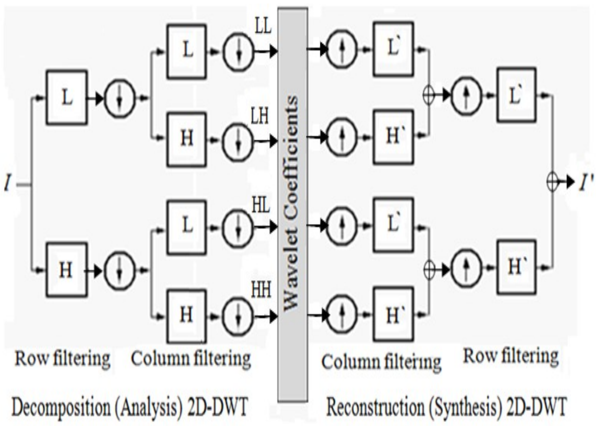

Figure 1 2D-DWT decomposition and reconstruction.

2.1. Daubechies 9/7

The popular CDF 9/7 filter bank developed by Cohen, Daubechies and Feauveau possesses linear phase and excellent image compression performance. This wavelet filter bank is one of the most widely used wavelet in the image compression applications. The analysis filter coefficients for such filter bank used for the dyadic decomposition are given in Table 1. The analysis low-pass filter has 9 coefficients, while the synthesis filter has 7 coefficients [10].

3. Fractional Wavelet Transform

In general, traditional compression algorithms are not applicable for current sensor nodes, since they have limited resources. Basic reasons for this problem are algorithm size, processor speed, and memory access [11]. In addition, the problem of energy consumption reduction for wireless sensor networks is addressed for sensors that has limited power and acquires data that should be transmitted to a central node. Traditional wavelet transform implementations require the whole image to be buffered, keep the entire source and/or destination image in memory.

It should be noted that filtering in the horizontal direction is very simple and requires only a single row to be read each time, while filtering in the vertical direction requires the whole image to be read, which is more cumbersome [5]. Concerning memory accesses, each pixel is read and written twice [11]. Assuming that an N*N-sized image is to be compressed, a memory space of size ($2N^2$) pixels is needed during the first 2-D level transformation to store the temporary data after the first and second 1-D DWT decomposition stages. This leads to four output subbands (HH, HL, LH, and LL as shown in Figure 1). For the next 2-D level, only LL subband will be used, so it is the one which must be kept in memory.

The line-based wavelet transform is applied to overcome the problem of memory limitations, providing exactly the same transform coefficients as the traditional wavelet transform implementation. To reduce the amount of memory required, we may keep in memory only the part of image strictly necessary (*i.e.*, LL subband or even less). But because the line-based wavelet requires long time to execute each line individually, the processing is too long. A solution for this problem is fractional wavelet which is used to fraction the image into 9 lines to be processed together using filter 9/7 on images of N^2 size [3]. This solution was introduced to reduce the transpose computing latency which is the problem of line-based method. The main advantage of fractional algorithms is their lower memory requirements compared with the traditional wavelet transform. There is no need to read the whole image. As soon as the image is captured, the processer can directly start work on it and only some portion of the image may be kept in memory.

In the fractional implementation of *Ref.* [3], the buffers of the first level wavelet transform contain 9 lines from original image width to store image coefficients.

Table 1 Daubechies 9/7 analysis and synthesis filter coefficients

	Analysis Filter Coefficients	
Index *i*	**Low-Pass Filter L(i)**	**High-Pass Filter H(i)**
0	0.6029490182363579	1.115087052456994
± 1	0.2668641184428723	0.5912717631142470
± 2	-0.07822326652898785	-0.05754352622849957
± 3	-0.01686411844287495	0.09127176311424948
± 4	0.02674875741080976	
	Synthesis Filter Coefficients	
Index *i*	**Low-Pass Filter L'(*i*)**	**High-Pass Filter H'(*i*)**
0	1.115087052456994	0.6029490182363579
± 1	0.5912717631142470	0.2668641184428723
± 2	0.05754352622849957	-0.07822326652898785
± 3	-0.09127176311424948	0.01686411844287495
± 4		0.02674875741080976

The width is then halved at every level. Instead, a new splitting scheme is used in this paper with a buffer of size (8*M) to process images of any size (N*M). Since image sensors usually capture images in even dimensions, 8 lines is used to reduce image reading latency. 2D-DWT is applied on 8 lines in each step. Another two destination buffers are required. The first buffer is of size (4*M) that forms rows for LL & HL subbands and another one of size (4*M) for LH & HH subbands. All these three buffers are updated each 8 lines with the new input lines that are stored in SD-RAM or in external flash memory. By this method, a memory or a cash requirement for image processing will be of N/8 lines instead of N lines. That allows large image size processing as long as there is no need to keep the whole image in memory. As compared to *Ref.* [3], such algorithm will further reduce the required potential of the memory, CPU and power energy of digital devices or the camera sensors.

4. Fractional Wavelet Artifacts

Block (or tiling)-based transform uses non-overlapping blocks 8*8 block size, which are processed independently, as they are entirely distinct images. The tile component is the basic unit of the original or reconstructed image, although tiling also reduces memory requirements [8]. It produces unpleasantly visible degradation at high compression ratio of the block transform coding such as (DCT), which is the blocking artifact. The degradation results because correlation among spatially adjacent blocks is not taken into account in coding. As a result block boundaries become visible after reconstructing the image [12]. Over the last several years, many techniques have been applied to reduce blocking artifact. Some of these techniques are based on reducing the blocking artifact in smooth region of the image [13], but fail in terms of computational complexity; others proposed approaches reduce the blocking artifact but also reduce image sharpness. Chen et al [12] proposed a post processing filter of three modes to reduce blocking artifact between two adjacent blocks using a fixed threshold values to classify the image into three frequency modes (smooth, intermediate, and non-smooth mode for low-frequency, mid-frequency, and high-frequency regions, respectively), to modify the current pixel values and its neighbors' across the block vertical and horizontal boundary. The modification is applied according to local image features after computing the difference between two pixels across the boundary. In an analogy to the prescribed DCT blocking artifacts; the application of fractional wavelet have some effects on image quality, because wavelet transform is applied on a fraction of an image each time, then all fractions are combined to form the complete constructed image which causes a little loss of correlation between every two adjacent fractions, resulting in some horizontal artifact at some pixels on the fraction boundary.

Since fractional wavelets use block size 8*N, this may reflect artifacts at the end line of some fractions. For multi-level wavelet and after image reconstruction, fractional artifact near last line in the fraction boundary can be noticed. Thus, an adaptive region-based fractional wavelet transform deblocking filtering process is proposed and discussed in the next sections where subjective and objective picture quality can be significantly improved by decreasing the fractional artifacts.

5. Region –Based Fractional Deblocking Filter

In general the proposed fractional artifact reduction approach is derived from the approach used in [12] by means of using a modified version of the three types of filters according to the nature of the processed area (smooth, non-smooth, and intermediate), to modify the current pixel and its neighbors. If the modifications are carried out without considering the nature of current pixels, it may result in additional artifacts, therefore before applying the modifications, it must be decided whether the edge is genuine due to vertical change in pixel intensity value or it has resulted from blocking artifact between two neighboring fractions. The main modification in this approach is accomplished by, First: applying the deblocking filter described in [12] only at the horizontal boundary as in Figure 2. Second: to reduce computation complexity and processing time while keeping the original image details, the modification on the intermediate mode is performed by using the mean average of the two adjacent pixels at the fraction boundary instead of using low pass filter for window of size 3*3 as in Ref. [12]..Third: the main improvement in the proposed approach is gained by using adaptive thresholds that differs in each fraction according to the nature of the existing local region in specific and the nature of image in general, instead of using fixed thresholds for all types of image. That is why called region – based fractional wavelets.

Using accurate thresholds will prevent degrading real edge sharpness. To set a threshold value that can reflect the amount of detail of the processed area, let P a set of the difference values *fi* between every two successive neighboring pixels across the boundary such that:

$$P = \{f_i\} \quad for\ i = 1 \text{ to } 6 \qquad (1)$$

Three considerations may also be taken into account. First: the human visual system (HVS) is more sensitive to blocking artifacts in flat or smooth regions than in complex regions, *i.e.* containing image details and edges [12]. Therefore, six pixels across the boundary at the existing regions are involved in filtering operation. This is accomplished by setting the threshold value to the minimum difference value in P. Second, in non smooth regions and complex areas, fewer pixels should be involved in the filtering operation to preserve the sharpness of image details and edges. Therefore, only four pixels across the boundary are modified with the maximum difference value of P being set as a threshold. Third, in case of intermediate area, the average of two neighboring pixels across the horizontal boundary is calculated instead of using windows of 3*3. The involved pixels are highlighted in Figure 2. This technique will preserve the details with blurred image avoidance leading to a modified image quality. That because such operations reduce the fractional effects without degrading the image details, or changing the smooth regions to complex regions and vice versa. It is also simple and results in a low computational complexity.

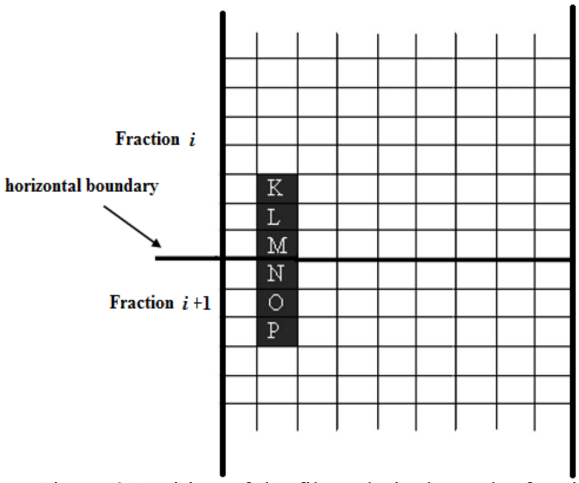

Figure 2 Position of the filtered pixels on the fraction.

6. Results and Discussions

In this paper, traditional wavelet, fractional wavelet and region-based fractional wavelet decompositions are implemented on gray images with different sizes and decomposition levels. The performance evaluation of the outputs is based on visual evaluation and on objective measures by computing the Peak Signal to Noise Ratio (PSNR) between original image I and reconstructed image $I^{'}$ using the followings:

$$PSNR = 10.\log_{10}\left(\frac{255^2}{MSE}\right) \quad (2)$$

where

$$MSE = \frac{1}{\text{N.N}}\sum_{i=0}^{\text{N}-1}\sum_{j=0}^{\text{N}-1}[I(i,j) - I'(i,j)]^2 \quad (3)$$

Typical wavelets are applied on images of sizes N*N. In this paper, images with different sizes (N*M) are used by applying symmetric extension on the boundary. In general there will be discontinuities at these boundaries. Test images from different categories (real time images, natural images, standard test images) are used. Figures 3 shows two standard test images 512*512 pixel-sized "Goldhil.tiff" and 229*255 pixel sized image "Bird.jpeg" with the result of applying level 2 wavelet 9/7 decomposition, fractional wavelet and the enhanced fractional wavelet-based decompositions. Figures 4 shows the PSNR values using wavelet, fractional wavelet transform for levels (1 to 7) and the proposed approach to reduce fractional artifact on the mentioned images using the wavelet CDF 9/7 filters. From Figure 4, it can be seen that at low-level decompositions, the PSNR values of the resulting images in the proposed region-based fractional wavelet outperform their corresponding values of the traditional fractal wavelet. While for high-level decompositions, the same values are maintained. The execution time after level 7 reconstruction post-processing for image " Bird " is 0.0250 second and it is 0.0270 second for image " Goldhil ".

It should be noted that fractional artifact on smooth area is more visible than area with very high details. Image "Bird" proves this, where higher artifact can be noticed on its face (highlighted by rectangle as in Figure 3-d). The efficiency of the proposed algorithm is granted in such portion, the fraction boundary became smooth and not visible, while fractional artifact on image "Goldhil" is less visible. The proposed algorithm keeps the image intensity almost unchanged reserving the image details and edge sharpness without causing blurring effect or any post processing degradation. The strength of the proposed modification comes from the use of adaptive threshold values. Those thresholds lead to apply the suitable filtering process at each fraction boundary according to area nature (Smooth, Non-smooth, Intermediate), so that all fraction boundaries will be harmonized with the entire image.

7. Conclusions

An adaptive region-based fractional wavelet transform has been presented and tested on different images to serve for low cost camera sensors with limited memory sizes.

The proposed solution has been applied after the decomposition process. It has been shown that such solution leads to the best image quality, since it reduces the fractional effects without degrading the image details. From the test experiments and to achieve better image quality, the proposed region-based filtering strategy is applied at the fraction boundary only leaving the inter-block contents unchanged. That is to reduce artifact across the fraction boundaries with the reservation of original image details at a very little execution time. That's why the resulting images show better image quality compared to traditional fractional wavelets.

Figure 3 The resulting images of applying 2- level fractional wavelet and proposed technique.(a,e) original images. (b,f) 2-level decomposed images. (c,g) reconstructed images. (d,h) post-processed .

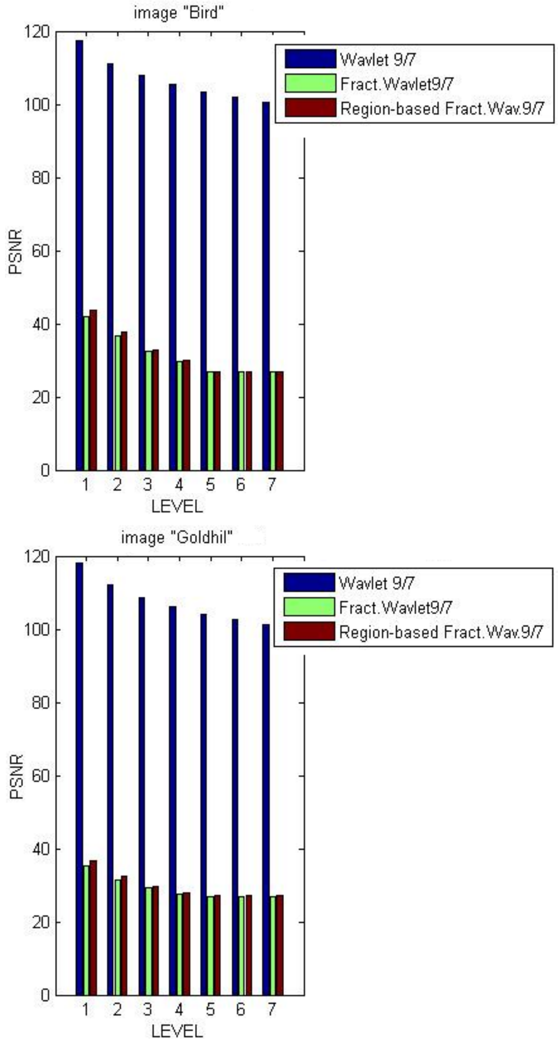

Figure 4 PSNR values of the tested wavelet 9/7 methods and the enhanced images "Bird" and "Goldhil"

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