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Efficient fuzzy composite predictive scheme for effectual 2-D up-sampling of images for multimedia applications ☆

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ABSTRACT

In this paper, a highly nonlinear, fuzzy logic based, composite scheme is proposed by combining a pre-processing and a post-processing operation to efficiently restore high frequency (HF) and very high frequency (VHF) details in an up-scaled image. The blurring in case of an up-sampled image is caused by the degradation of HF and VHF image details that correspond to fine details and edge regions during the up-sampling process. The degradation of HF and VHF image details is more significant than that of the flat and slowly varying regions. In order to resolve this problem effectively, a fuzzy composite scheme is developed which is based on the inverse modeling approach of HF degradation. During the pre-processing operation, the VHF components of an image are boosted up using recursive Laplacian of Laplacian (LOL) operator prior to image up-scaling. Subsequent to the image up-scaling, a fuzzy local adaptive Laplacian post-processing scheme is used which enhances the HF image details more than the low frequency image details based on local statistics in the up-scaled image. The HF restoration performance of the fuzzy based composite scheme is enhanced by improving its nonlinearity through the variations of different parameters of the fuzzy inference system (FIS) such as slope, width and the number of input-, and output membership functions. The effective fusion of pre-processing and post-processing operations makes the proposed scheme much effective to tackle the non-uniform blurring than the standalone pre-processing and post-processing techniques. Experimental results reveal that the proposed composite scheme gives much less blurring in comparison to the standalone schemes and performs better than most of the widely used interpolation schemes in terms of objective and subjective measures.

1. Introduction

Image up-sampling has been a topic of great interest in recent years and is used for generating an up-scaled image from a low resolution (LR) image data. It is sometimes very essential for further processing, analysis and interpretation for a specific application. Image up-sampling through interpolation aims to compute up-scaled images containing accurate and precise details of an original LR image and at the same time should also be able to preserve the smoothness and fast changing variations in the image regions while producing an up-scaled image.

Sometimes, to acquire more information from satellite, computer tomography, X-ray and astral images, it is necessary to up-scale the captured image for subsequent analysis and interpretation. In various video surveillance applications, it is imperative to improve the resolution of the captured sequences for inspection and recognition. Up-scaling of medical images is very necessary for proper diagnosis of a problem.

Image up-sampling is very essential to avoid the requirement of very densely packed, high resolution image sensors for capturing a high resolution (HR) image. The cost of densely packed charge coupled device (CCD) is too expensive. Therefore, by using less or moderately dense image sensors, it is possible to generate a HR image using 2-D interpolation and so is cost-effective. 2-D interpolation is a promising trend in the field of Infrared imaging because IR images usually have low resolution due to the high cost of IR sensors.

There is a great need in developing techniques to facilitate flexible image/video format conversion among various multimedia terminals such as digital cameras, cellular phones, personal digital assistants (PDAs), computers and high-definition televisions (HDTVs). Image up-sampling and down-sampling through interpolation plays a major role in resolving these issues. Image interpolation is a popular technique for image manipulation and processing. Its most common application is to provide enhanced visual effects

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after resizing a digital image for display or printing. In recent years, the increasing popularity of consumer multimedia products has made imaging and display devices ubiquitous. So, image interpolation is becoming increasingly important. 2-D up-sampling has huge applications in the areas like image coding, image resizing, image manipulation, face recognition and surveillance. Besides, image interpolation is also used in image or video enlargement in medical imaging, military applications, space imagery, satellite imaging, remote sensing and various biometric applications. Almost all interpolation schemes, available in the literature, yield blurring effect. In addition, discrete cosine transform (DCT) based interpolation schemes produce ringing artifacts. The blurring becomes more significant in the edge and fast changing regions and is less in the slowly varying, flat regions.

Various interpolation techniques have been developed so far to resolve the aforesaid issues. Conventional polynomial-based interpolation methods such as Bilinear, Bicubic and Spline interpolation are often used due to their computational simplicity [1–6] for various real-time applications. Lanczos is another spatial domain interpolation technique which is implemented by multiplying a sinc function with a sinc window which is scaled to be wider and truncated to zero outside a range [7,8]. Even if Lanczos-3 interpolation [9,10] gives good results, it is slower than other approaches and provides a blurring effect in the reconstructed image. Therefore, polynomial functions are not good at modeling the signal's discontinuities (e.g. edges). Hence, the conventional polynomial-based interpolation methods often produce annoying artifacts such as aliasing and blur around the edges.

Since edges are visually attractive to the human perceptual system, some edge-directed interpolation methods [11–14] have been developed to address the edge reconstructions. In fact, the adaptive polynomial-based methods can be regarded as edge-directed methods as well. The basic idea of edge directed methods is to preserve the edge sharpness during the up-sampling process. The intuitive way is to explicitly estimate the edge orientation and then interpolate along the edge orientation. New edge-directed interpolation (NEDI) uses the FIR Wiener filter, equivalently, the linear minimum mean squares error estimator [15–18] for linear prediction. NEDI makes use of the LR image to estimate the HR co-variances for the FIR Wiener filter. The soft-decision adaptive interpolation (SAI) [19] has been proposed to interpolate a block of pixels at one time using the idea of NEDI. It has the benefit of using the block-based estimation, by constraining the statistical consistency within the block region, which comprises both observed LR and unobserved HR pixels. It is well known that the least squares estimation is not robust to outliers and hence the weighted least squares estimation has been proposed to improve the accuracy and robustness of the SAI [20,21]. The robust soft-decision adaptive interpolation (RSAI) incorporates the weights to all residuals in the cost function of the SAI.

Many approaches for image resizing have been developed in transform domain [22,23]. Up-sampling in DCT domain is implemented by padding zero coefficients to the high frequency side. Image resizing in DCT domain shows very good result in terms of scalability and image quality. However, these techniques although improved, suffer through undesirable blurring and ringing artifacts and computationally more complex than various spatial domain interpolation techniques [24–27].

Spatial down-sampling is a simple technique for image/video compression. Even with the latest video coding standards like H.264/advance video coding (AVC) and H.265/high efficiency video coding (HEVC), intra-frame processing may be employed to spatially downsample a video. Under such circumstances, a decoder must employ a spatial upsampler and a suitable interpolation scheme. Yan et al. have proposed various parallel frameworks [35–38] and de-blocking filter [39] for fast and efficient implementation of H.265/HEVC codecs. Intra-frame interpolation, followed by up-sampling, on HEVC architecture will further improve the coding efficiency. Hence, efficient 2-D interpolation is a relevant topic of research even with present video compression schemes developed on HEVC platform.

1.1. Related work

Various adaptive and edge directed interpolation schemes have been developed to tackle the blurring problem effectively. An adaptive technique makes use of Gaussian edge directed interpolation to determine the precise weights of the neighboring pixels. The standard deviation of the interpolation window determines the value of sigma for generating Gaussian kernels. Therefore, the proposed scheme adaptively applies different Gaussian kernels according to the computed standard deviation of the interpolation window. Laplacian is applied to the image generated by Gaussian kernels to enhance the visual quality of the output image [12].

Different pre-processing and post-processing algorithms have been developed in spatial domain so as to counter the blurring problem in an up-sampled image [28–30]. If the processing is done prior to image up-scaling, then it is considered as a pre-processing operation. On the other hand, if the processing is performed after image up-scaling, then the method is taken as a post-processing operation. In case of a crisp local adaptive unsharp masking operation, the LR image is sharpened using adaptive, crisp mapping technique as per the local statistics of an image prior to image up-sampling process [28]. However, this method lacks in adaptability to varying constraints such as the degree of zooming and the image types. The limitation due to crisp mapping process is eliminated using direct mapping approach. In this case, the low resolution images are locally sharpened as per local statistics on direct mapping prior to image up-sampling process [29]. Nevertheless, the method is a two-pass scheme and computationally more complex than the former.

Furthermore, a fuzzy unsharp masking based pre-processing algorithm has been developed [30] in which the local HF contents are enhanced considering local statistics using fuzzy weighted unsharp masking. Although, the fuzzy pre-processing algorithm gives better performance than crisp scheme, it fails to give any further improvement than the direct mapping approach. In the above local pre-processing schemes, there is no considerable improvement in the restored image quality and HF preservation in the up-scaled images. However, this problem has been resolved effectively in case of a local post-processing algorithm at a cost of increased computational complexity. The computational complexity of the post-processing algorithm increases because of increased size of the up-sampled image. In this post-processing algorithm, an up-scaled image is locally sharpened using local adaptive Laplacian to enhance the high frequency details as per local variance so as to reduce blurring in a 2-D up-sampled image [31].

In addition, an error based global pre-processing scheme [32] has been developed to tackle the blurring problem more effectively and is very much similar to unsharp masking operation. It extracts the degraded high frequency information by intentionally down-sampling the given low resolution image and then restoring it back to its original size using Bicubic interpolation. The lost high frequency information i.e. the prediction error is obtained by subtracting the restored, reconstructed image from the original. Hence, by superimposing the weighted version of the lost high frequency details with the original prior to any further up-sampling, the degree of blurring can be reduced in the up-sampled, high resolution image. This algorithm is computationally less complex because of being a global pre-processing scheme. The processing time is also less because the algorithm is operated on a low resolution image prior to image up-sampling. However, it lacks the