A VQ-Based Blind Super-Resolution Algorithm

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Abstract. In this paper, a novel method of blind Super-Resolution (SR) image restoration is presented. First, a learning based blur identification method is proposed to identify the blur parameter in which Sobel operator and Vector Quantization (VQ) are used for extracting feature vectors. Then a super-resolution image is reconstructed by a new hybrid MAP/POCS method where the data fidelity term is minimized by $l_1$ norm and regularization term is defined on the high frequency sub-bands offered by Stationary Wavelet Transform (SWT) to incorporate the smoothness of the discontinuity field. Simulation results demonstrate the effectiveness and robustness of our method.

1 Introduction

In many image applications such as remote sensing, military surveillance, medical diagnostics and HDTV, SR images are often required. However, the quality of image resolution depends on the physical characteristics of the imaging devices, and it is hard to improve the image resolution by replacing sensors because of the cost or hardware physical limits. Super-resolution image reconstruction is one promising technique to solve the problem which uses digital image processing techniques to obtain an SR image (or sequence) from several low resolution samples of the same scene. It has been one of the most active research areas in the field of image recovery.

The super-resolution idea was first addressed by Tsai and Huang \cite{Tsai1990}, who used the aliasing effect to restore a high-resolution image from multiple low-resolution (LR) images. Many different methods were proposed then in this field, such as iterative back projection (IBP) \cite{Reid1993}, projection onto convex set (POCS) \cite{Parr2000}, Bayesian estimation \cite{Heo2000}, etc. However, only a few address the problem of blind SR. Meanwhile, SR restoration can be considered as a second-generation problem of image recovery, therefore some methods of image recovery can be extended to solve SR problem. In \cite{Nakagaki2001}, a VQ-Based blur identification algorithm for image recovery was proposed by Nakagaki. But in this method if the variance of the band-pass filter was not chosen properly, it was hard to identify blur parameter.

In this paper, we propose a blind SR algorithm by improving the VQ-based approach. In our method, Sobel operator is introduced for extracting feature vectors and DCT is applied to reduce the dimensionality of the vector. After blur identification,
we also propose a new algorithm for SR restoration by combining $l_1$ norm minimization and stationary wavelet transform. Simulations show that our method is robust to different types of images and different noise models. Also, it has fast convergence performance and low complexity.

The paper is organized as follows: The proposed SR blur identification algorithm is presented in section 2. Section 3 describes the SR restoration method. Simulations in section 4 show the effectiveness of our method. Section 5 concludes this paper.

2 Blur Identification

At present, there are two super-resolution models: the warping-blurring model and the blurring-warping model. The former model coincides with the imaging physics but it is usable only if the motion among SR images is known a priori, and the latter model is more appropriate when the motion has to be estimated [8]. In the following, the warping-blurring model is taken as an example to discuss the problem. The relationship between the low-resolution images and the high resolution image can be formulated as [4]:

$$Y_k = D_k H_k F_k X_k + E_k$$  

where $Y_k$ is the $M_1 M_2 \times 1$ lexicographically ordered vector containing pixels from the $k$th LR frame, $X$ is the $N_1 N_2 \times 1$ lexicographically ordered vector containing pixels from SR image, $E_k$ is the system noise with the size $M_1 M_2 \times 1$, $D_k$ is the decimation matrix of size $M_1 M_2 \times N_1 N_2$, $H_k$ is the blurring matrix of size $N_1 N_2 \times N_1 N_2$, known as the Point Spread Function (PSF), $F_k$ is a geometric warp matrix of size $N_1 N_2 \times N_1 N_2$, $1 \leq k \leq K$ and $K$ is the number of low-resolution images.

In many practical situations, the blurring process is unknown or is known only within a set of parameters. Therefore it is necessary to incorporate the blur identification into the restoration procedure.

2.1 The VQ-Based Blur Identification Algorithm

Vector quantization is a technique used in the data compression field. In [5], it was applied to identify blur parameter of the degraded image where different vector represents different local characteristics of the image. The method consists of two stages: codebook design and blur identification. Details are shown as in Fig.1.

Assuming that the blurring process is known and blur function is parameterized by the parameter $i$. A number of VQ codebooks, each corresponding to a candidate blurring function are designed using band-pass filtered prototype images. A codebook with the minimum average distortion for a given degraded image is selected and the blur function used to create the codebook is identified as the unknown blurring function.