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Robust single image super resolution using neighbor embedding and fusion in wavelet domain☆

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ABSTRACT

This paper proposes methods for super resolving single noisy low resolution images. Even if single image super resolution has been a topic of research for last few decades, super resolution of noisy low resolution images is still a challenging problem. Most of the state of the art super resolution algorithms will fail to perform if significant amount of noise is present in the observed image. In this paper, we propose a denoised patch dictionary based single image super resolution algorithm. To enhance the robustness to noise performance, this method is further modified by using a wavelet based fusion algorithm which combines the result of proposed method with direct super resolved image, and super resolved image after denoising to preserve the finer details of the super resolved image. The proposed methods are applied on the commonly used test images. The results validate that the proposed methods show improvement over the existing techniques.

1. Introduction

Demand for high resolution (HR) images are increasing due to the presence of rich details compared to the low resolution (LR) image. HR imaging sensors are fabricated with large number of pixels per unit area. But the smaller sensing elements can receive less amount of light which results in low signal to noise ratio values [1]. An alternate approach to acquire HR image is to use signal processing techniques to reconstruct HR images from low resolution observations. This process of reconstructing HR images from LR observations is called super resolution (SR). LR images has fewer details than HR images, thus SR algorithms will regenerate the HR images by adding these missing details [2]. Image super resolution is the inverse problem of estimating the ground truth image from LR observations. A simplified image observation model is given by,

$$\mathbf{x} = \mathbf{DBMz} + \eta \tag{1}$$

where, $\mathbf{x}$ is the observed LR image, $\mathbf{z}$ is the ground truth, $\mathbf{D}$ is the sampling matrix, $\mathbf{B}$ stands for the blurring model, $\mathbf{M}$ represents the warping and η is the additive noise. A number of research work has been reported to address this problem. Majority of these methods fail to perform, when significant amount of noise is present in the observed image. But LR observations inevitably contain noise and only a few has attempted to mitigate the effect of noise from the reconstructed HR image. SR algorithms are broadly classified into single frame SR and multi frame SR. Multi-frame SR algorithm utilize multiple LR observations of same scene and these images are combined together to form HR image. Multiple LR observations

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may have sub-pixel shifts between each other. So the additional details in each observations are merged together. SR algorithms finds application in multitude of domains ranging from photo enhancements, microscopy, etc. to medical diagnosis [3]. Medical diagnosis based on image analysis is now very common and many such techniques are available in literature [4]. Appropriate SR algorithms can be used to improve the performance of these algorithms.

1.1. Single image super resolution

Many real world applications, like high definition displays, require reconstruction of HR image from single observations. Therefore, single observation based SR methods become a hot topic of research in recent years. In single image SR algorithm (SISR), HR image is estimated from a single LR observation [3]. There are different categories of SISR algorithms. Reconstruction based methods use the LR patches to synthesis the SR image. These methods address the aliasing issues caused during the acquisition of LR image. Learning based methods acquire the relationship between LR and HR images from examples and this information is used to reconstruct the HR image. The learning algorithm performs well with low dimensional signals, thus it is more effective when applied on small segments or patches of image rather than applying on the entire image [5]. Therefore patch based algorithms are very popular in super resolution community.

Many of the learning based methods model HR-LR relationship with the help of a set of representative vectors or atoms. Collection of such atoms suitable for representing LR and HR patches are called dictionaries. These atoms could be abstract mathematical basis vectors like DCT basis, wavelet basis, etc. or set of vectors chosen from example training set. The patches can be represented with the dictionary atoms using least squares [6], ridge regression [7], sparse representation [8], etc.. Sparse representation based methods with proper regularization term [9], reported relatively better results compared to least square and ridge regression based techniques [3]. In certain algorithms employing sparse representation, the dictionaries are learned from large number of training examples using dictionary learning algorithms like KSVD [10], coupled dictionary learning [11], etc., during the training phase. Neighbor embedding based algorithms use sufficiently large set of appropriately selected samples from the collection of training patches as dictionary [6,12]. The selection of the samples can be further refined using the dimensionality reduction techniques like Multi-view Sparsity Preserving Projection [13], Locality Structured Sparsity Preserving Embedding [14], etc.

Another group of algorithms rely on the concept of self-learning, which utilize the redundancy of patches in the LR image and its scaled versions to reconstruct the super resolved image [15,16]. A number of SR algorithms are reported in literature which makes use of the neighboring patches in the same image or in a training set [17]. Peleg and Elad [18] proposed a statistical prediction based method for SR using sparse representation and a Restricted Boltzmann Machine (RBM) based predictor. This deep learning based approach gives promising performance and we used this method as the reference SR algorithm. Recently many deep learning methods has been proposed for SR. These methods learns the LR to HR mapping into deep networks and it is used for synthesizing the HR images [19]. LeNm-RBM algorithm proposed by Rahiman and Sudhish [12] combines the neighbor embedding with self learning concept and uses RBM predictor to synthesis HR image. Methods proposed in this paper utilize the concept of neighbor embedding and sparse representation, to synthesise HR image.

1.2. Noise robust single image super resolution

Although many SR methods are popular in research community, the practical use of these algorithms are limited due to the inability to deal with noisy images. A common practice used for noisy images is to perform denoising of noisy input image and then apply SR. But the process of denoising will remove noise as well as some useful details in the image. A noise robust method should retain the high frequency details in the image while carefully removing the noise. Sparse representation based methods are shown immune to small amounts of noise [8]. But as the noise level increases, the performance of such algorithms drop drastically. Sing et al. [20] presented a hybrid approach for noisy image SR which utilizes the result of SR on noisy image as well as the result of SR on denoised image. Multiple constraint based merging of the results produce better output than the constituent methods.

Mandal et al. [21] describes a non-local mean and sparse representation based method for super resolving noisy images. They demonstrate the dependence of the ratio of singular values obtained in singular value decomposition (SVD) on the amount of noise present. A corrupted dictionary based approach in a position patch based locality constraint framework was proposed by Rohit et al. [22] for noisy face image SR. Though this method is giving promising results in face image SR, it cannot be extended to generic image, as the patches of different images at a given position are not necessarily similar. But this work motivated us to use the denoised LR training set in a neighbor embedding framework.

1.3. Major contributions

Image denoising is a well studied topic and a number of such algorithms are available in literature. The power of these algorithms can be effectively utilized to develop a robust SR methods. Our contribution in this paper is a method for SR in which the existing denoising and super resolution algorithms are combined to get the benefits of both. In this paper, we propose a neighbor embedding based image SR with denoised LR patches and this method is named as DnSR. By using denoised patches, we keep the mapping between HR and denoised LR patches in the dictionary. Result of this method is

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