J. Vis. Commun. Image R. 40 (2016) 656–670

Contents lists available at ScienceDirect

J. Vis. Commun. Image R.

journal homepage: www.elsevier.com/locate/jvci

Multiframe super-resolution based on half-quadratic prior with artifacts suppress

Renchao Jin [a], Shengrong Zhao [b,a], Xiangyang Xu [a], Enmin Song [a,*]

[a] School of Computer Science and Technology, Huazhong University of Science and Technology, Wuhan 430074, China
[b] School of Information, Qilu University of Technology, Jinan 250353, China

ARTICLE INFO

Article history:
Received 6 January 2016
Revised 8 August 2016
Accepted 10 August 2016
Available online 11 August 2016

Keywords:
Super-resolution
Variational Bayesian inference
Regularization
Discontinuity-preserving
Artifacts-suppressing

ABSTRACT

The multiframe super-resolution (SR) technique aims to obtain a high-resolution (HR) image by using a set of observed low-resolution (LR) images. In the reconstruction process, artifacts may be possibly produced due to the noise, especially in presence of stronger noise. In order to suppress artifacts while preserving discontinuities of images, in this paper a multiframe SR method is proposed by involving the reconstruction properties of the half-quadratic prior model together with the quadratic prior model using a convex combination. Moreover, by analyzing local features of the underlined HR image, these two prior models are combined by using an automatically calculated weight function, making both smooth and discontinuous pixels handled properly. A variational Bayesian inference (VBF) based algorithm is designed to efficiently and effectively seek the solution of the proposed method. With the VBF framework, motion parameters and hyper-parameters are all determined automatically, leading to an unsupervised SR method. The efficiency of the hybrid prior model is demonstrated theoretically and practically, which shows that our SR method can obtain better results from LR images even with stronger noise. Extensive experiments on several visual data have demonstrated the efficacy and superior performance of the proposed algorithm, which can not only preserve image details but also suppress artifacts.

1. Introduction

Super-resolution (SR) [1] is an important branch in image fusion technology, which aims to reconstruct a high-resolution (HR) image from a single or a set of low-resolution (LR) images. The SR concept was first proposed by Tsai and Huang in [2]. This technique has been widely used in many applications, such as computer vision, medical imaging, public safety, and military reconnaissance.

In some applications, only one LR image is available. Inspired by this, the single-frame SR method attracts increasing research attention. The simplest methods are the interpolation-based approaches, such as the bicubic interpolation. However, these methods often lead to blurring the edges and introducing artifacts in the results. More advanced single-frame SR methods are proposed. In [3], an iterative multiscale semilocal interpolation method is proposed to generate the HR image by using a maximum a posteriori (MAP) estimation. In this estimation, the top texture-relevant LR pixels are used to construct a data fidelity term, and a bilateral total variation is used as the regularization term. Learning-based SR methods are popular in many applications recently. In [4], a statistical learning method for SR with both global and local constraints is proposed. The global parametric constraint guarantees the super-resolved global image to agree with the sparse property of natural images, and the local non-parametric constraint is used to infer the residues between the image derived from the global constraint and the HR image. A statistical prediction model based on sparse representations of LR and HR image patches for single image SR is proposed in [5], which goes beyond the standard assumption of sparse representation invariance over a low and high resolution dictionary pair. Inference with their model leads to a low-complexity scale-up scheme that has the useful interpretation of a feedforward neural network. In [6], a self-similarity based single-frame SR is proposed. The internal patch search space is expanded by allowing geometric variations, and the additional affine transformations is incorporated to accommodate local shape variations. In [7], a joint SR and smoothing framework is proposed with an L0 gradient smooth constraint. A robust coupled dictionary learning method with locality coordinate constraints is introduced to reconstruct the HR depth map. And an adaptively regularized shock filter is incorporated to simultaneously reduce the jagged noise and sharpen the edges. Deep learning techniques have been successfully applied in image SR

* Corresponding author.
E-mail address: enmin_song@126.com (E. Song).

http://dx.doi.org/10.1016/j.jvcir.2016.08.006
1047-3203/

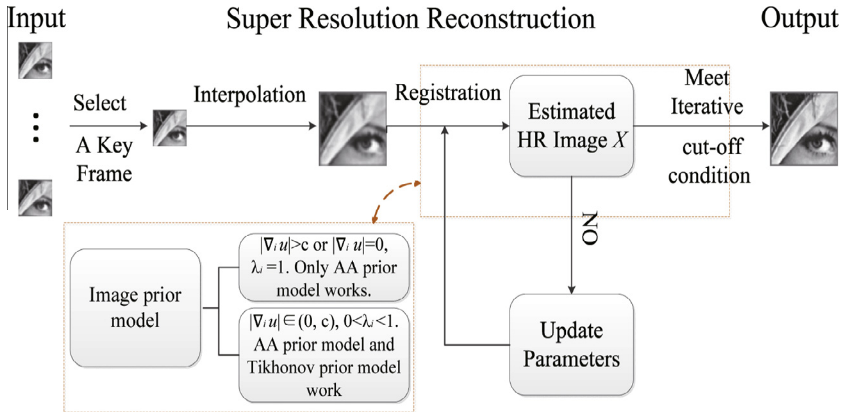

Fig. 1. The proposed framework.

problems. In [8], the authors argue that domain expertise represented by the conventional sparse coding model is still valuable, and it can be combined with the key ingredients of deep learning to achieve further improved results. They show that a sparse coding model particularly designed for super-resolution can be incarnated as a neural network, and trained in a cascaded structure from end to end. The method in [9] learns an end-to-end mapping between low- and high-resolution images, with little extra pre/post-processing beyond the optimization. This method also shows that conventional sparse-coding-based image SR methods can be reformulated into a deep convolutional neural network.

The multi-frame SR method requires a set of LR image as the input. And the regularization approach has become more popular due to its perfect mathematical background, and it can introduce a prior knowledge concerning the solution into the reconstruction process. Such as, the Tikhonov prior model proposed in [10] is quadratic, which assumes global smoothness, hence it often blurs image edges. On the other hand, the total variation (TV) type [11–13] model could preserve edges due to their non-quadratic form. However, this form has low penalty for the noise gradients, thus the noise would not be suppressed effectively and lead to artifacts [14]. The widely used markov random field (MRF) model [15] includes the Gaussian MRF model [16] and the Huber MRF model [17]. As in the Tikhonov model, the Gaussian MRF model is also quadratic, which may blur image edges. There exists a threshold in the Huber model, which can separate the quadratic and linear regions [18]. However, it is a difficult matter to choose a suitable threshold in actual experiment condition. Thus, the concept of discontinuity adaptive MRF model or edge-preserving regularization term [15,19,20] is becoming more adopted due to the usage of half-quadratic potential functions. In [21], the authors proposed a deterministic SR approach based on the bilateral edge-preserving (BEP) model and using such a potential function (called Yang potential function here). In [22], the traditional TV model is combined with the Frobenius norm regularization. And this method was proposed to preserve edges while avoiding staircase effects in the homogeneous regions of images without considering the motion estimation. In [23], Villena et al. considered the simultaneous auto regressive (SAR) model with quadratic form involving the TV type based SR method, which has been proved effective for the SR problem. However, the weighting parameter used to balance these two prior models has to be adjusted manually, which is a difficult matter in actual experiment condition. In [24], a prior model based on the Yang potential function was proposed, which was called the anisotropic adaptive (AA) prior model here. The aforementioned prior models are all half-quadratic, hence, they may not be possible to suppress noise, especially in presence of stronger noise.

The regularization approach includes the deterministic and stochastic regularization approaches. The basic idea of the deterministic regularization approach is to use the regularization strategy to incorporate the prior knowledge of the unknown HR image. The stochastic regularization approach, typically a Bayesian approach, provides a flexible and convenient way to model a prior knowledge concerning the solution, such as the MAP approach. In [25], the HR image is reconstructed by minimizing a MAP-MRF energy function with the linear truncated prior. And the method in [26] employs the MAP estimator and the sparse image priors to keep useful salient structures while suppressing noise. The estimation of hyper-parameters related to the noise model and the prior image model can also affect the reconstruction quality. The joint posteriori probability distribution of the HR image, motion parameters and hyper-parameters has a complex expression and the MAP can not solve this issue. Recently, the variational Bayesian inference (VBF) estimator has been introduced into the SR reconstruction technique [22,24,23,27,28], which approximates this complex joint posteriori probability distribution analytically by a tractable distribution.

In this paper, we extend the AA prior model using an extra quadratic function, and propose a variational Bayesian SR algorithm with a hybrid prior model using a convex combination scheme for HR image estimation. This approach efficiently interlaces the HR image estimation, the motion parameter estimation and the hyper-parameter estimation in a complete framework (Fig. 1). The numerical results show that our method achieves better reconstruction compared with the SR method under comparison. The contributions of this work are summarized as follows:

(1) Involve the reconstruction properties of the AA prior model together with the Tikhonov prior model using a convex combination.
(2) By analyzing local features of the underlined HR image, the two prior models are combined by using an automatically calculated weighting function, making both smooth and discontinuous pixels handled properly.
(3) To demonstrate the efficiency of the combination strategy, the theoretical and practical analysis is presented in this paper.
(4) The variational Bayesian inference (VBF) estimator has been used in this paper, and hence our approach is fully formulated in the framework of Bayesian statistics by the utilization of the Kullback-Leibler (KL) divergence. With VBF, the