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Noise robust position-patch based face super-resolution via Tikhonov regularized neighbor representation

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ABSTRACT

In human-machine interaction, human face is one of the core factors. However, due to the limitations of imaging conditions and low-cost imaging sensors, the captured faces are often low-resolution (LR). This will seriously degrade the performance of face detection, expression analysis, and face recognition, which are the basic problems in human-machine interaction applications. Face super-resolution (SR) is the technology of inducing a high-resolution (HR) face from the observed LR one. It has been a hot topic of wide concern recently. In this paper, we present a novel face SR method based on Tikhonov regularized neighbor representation (TRNR). It can overcome the technological bottlenecks (e.g., instable solutionand noise sensitive) of the patch representationscheme in traditional neighbor embedding based image SR methods. Specifically, we introduce the Tikhonov regularization term to regularize the representation of the observation LR patches, leading to a unique and stable solution for the least squares problem. Furthermore, we show a connection of the proposed model to the neighbor embedding model, least squares representation,sparse representation, and locality-constrained representation. Extensive experiments on face SR are carried out to validate the generality, effectiveness, and robustness of the proposed algorithm. Experimental results on the public FEI face database and surveillance images show that the proposed method achieves better performance in terms of reconstruction error and visual quality than existing state-of-the-art methods.

1. Introduction

In real-world scenarios, low-resolution (LR) images are generally captured in many electronic imaging applications, such as video surveillance, consumer photographs, satellite imaging, magnetic resonance imaging and video standard conversion. The resolution of captured images is limited by image charge-coupled device (CCD) and complementary metal-oxide semiconductor (CMOS) image sensors, hardware storage and other constraints in electronic imaging systems. However, high-resolution (HR) images or videos are usually desired and often required for the following face synthesis and analysis. Image super-resolution (SR) reconstruction, as an effective way to solve this problem, aims to reconstruct HR images from the observed LR ones. It can increase high-frequency components and remove the undesirable effects, e.g., resolution degradation, blur and noise (see Fig. 1). In this paper, we mainly focus on the face SR (sometimes also called face hallucination) problem.

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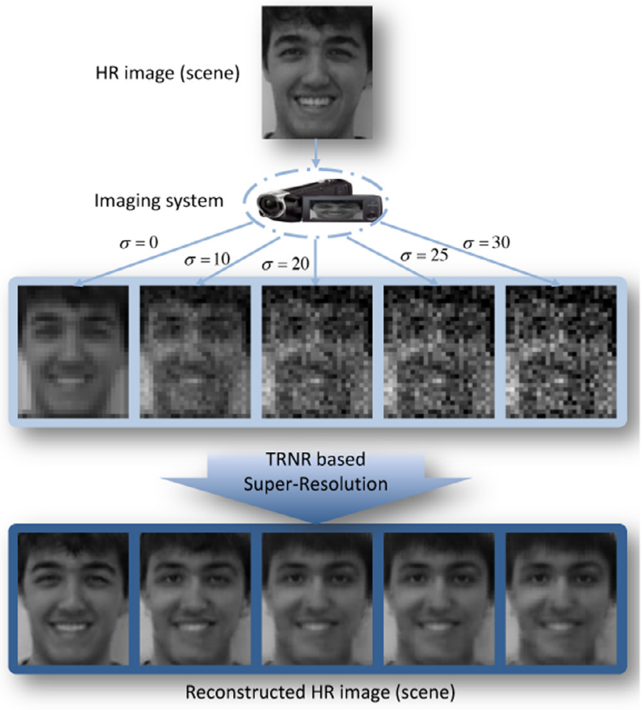

Fig. 1. Face SR reconstruction results of our proposed TRNR based method under different noise levels.

In the following, we will review some representative works in this field. For a more complete and comprehensive survey of image SR, please refer to [36].

1.1. Prior works

SR reconstruction is of great importance for various applications, and many algorithms have been developed in recent years. Generally speaking, they can be categorized based on their tasks, i.e., generic image SR [9,13,21,23,40,44,46,48] and domain-specific image SR focusing on specific classes of images such as faces [26,36] and text images [8].

In 2000, Baker and Kanade [2] developed a learning-based method named "face hallucination", which was the pioneering work on face SR. Given an input LR image, this approach infers the high frequency components from a parent structure with the assistance of training samples. Abandoning the Markov random field (MRF) assumption as in [9], this method is established based on training images using Gaussian, Laplacian and feature pyramids. Since the introduction of this work, a number of different methods and models have been developed for estimating the image information lost in the down-sampling process. These methods differ in ways of modeling the HR image. A successful face SR algorithm has to meet the global constraint (i.e., the results should have common human face characteristics) and the local constraint (i.e., the results should have specific characteristics of a particular face image). To fulfill these two constraints, Liu et al. [26] described a two-step approach integrating a principal component analysis (PCA) based global parametric model and a patch-based non-parametric Markov network. In the first step, the relationship between the HR face images and their smoothed, down-sampled LR ones is learned to obtain the global HR image. In the second step, the residual between an original HR image and its reconstructed one is compensated to learn the residual image. Both the work in [2] and [26] have shown that knowing an image containing makes it possible for an SR system to perform much better because the system can leverage regularities in face appearance to recover more details than creating from a general image model.

The above methods use probabilistic models and are based on an explicit resolution reduction function which sometimes is difficult to acquire in practice. Instead of using a probabilistic model, Wang et al. [37] proposed a face SR approach using eigentransformation algorithm, which can well capture the structural similarity of face images. This method treats the image SR problem as the transformation between LR images and their HR counterparts. An input LR image can be expressed as a linear combination of the LR images in the training set by using PCA. Then, the corresponding target HR image can be reconstructed by the same combination of the corresponding HR images in the training set. Following [37], many PCA based face SR methods have been proposed recently [4,30]. However, they are highly dependent on the training set since the core concept is to use a linear combination of the HR images in the training set to reconstruct the target HR face image. To achieve a good performance, these algorithms require that the training set size is very large, so that the test images have a great chance to be similar to the images in the training set.