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A new approach for face hallucination based on a two-dimensional direct combined model

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ABSTRACT

This study develops an example-based face hallucination system based on a novel two-dimensional direct combined model (2DDCM) approach. The 2DDCM model combines the low-resolution and high-resolution pairwise images in the training set in a combined (or concatenated) matrix form in order to better preserve the correlation between the two images during the system learning process. Notably, the images processed by the 2DDCM model have the form of two-dimensional (2D) matrices rather than one-dimensional (1D) vectors, and hence the facial geometry features in the vertical and horizontal directions can be more reliably extracted. The proposed hallucination system comprises two 2DDCM-based modules, namely a global module for global facial structure reconstruction and a local module for facial texture detail compensation. In implementing the local module, a 2DDCM-based bi-directional transformation method is adopted to identify the detailed facial textures which are lost in the global synthesis process. The experimental results show that the synthesized results obtained using the proposed 2DDCM framework are in good quantitative agreement with the ground-truth images. Moreover, the proposed framework demonstrates the ability to synthesize high-resolution facial images given only a small number of training pairs, even when the facial features, alignment and appearance of the testing image differ from those of the original training set. Finally, the 2DDCM representation ensures that the synthesized results better preserve the subject-specific characteristics of the input facial image, and therefore improves the performance of downstream applications such as automatic face recognition.

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1. Introduction

Face hallucination, i.e., reconstructing a high-resolution facial image from a given low-resolution image, is of great importance in many computer vision and multimedia applications, including face recognition, facial expression analysis, and facial pose estimation. Generally speaking, the performance of such schemes improves with the amount of information available in the input image. However, in practical applications, the input facial images often have a poor resolution. It is therefore necessary to develop more robust facial image synthesis systems capable of constructing high-resolution facial images from low-resolution input images.

Unlike the super resolution approaches proposed in [3,6,10,28], in which the target images have no particular structure, the images processed by a face hallucination framework are characterized by common facial structures and features (e.g., the eyes and nose). Consequently, various example-based face hallucination methods have been proposed which perform the synthesis process with the assistance of a set of low-resolution/high-resolution facial pairwise training samples. In general, the statistical information contained within these training images enables the facial structure of the input test image to be successfully preserved in the synthesized output image. However, the effectiveness of such learning-based face hallucination methods depends on the accuracy of the learning algorithms used to model the correlation between the low- and high-resolution facial images within the training dataset.

The face hallucination methods proposed in [24,26] use the eigen-transformation and Independent Component Analysis (ICA) kernel functions, respectively, to construct a subspace of the facial image which shares the same global facial geometry as that of the system input. Other example-based face hallucination methods with a similar objective have also been proposed in [1,8,14]. In such methods, the output high-resolution images are synthesized via a linear combination of the training samples. As a result, it is possible to synthesize new appearances which do not exist in the original training dataset. However, the synthesis results generated by a linear combination process are somewhat blurred. By contrast, the face hallucination methods proposed in [16,12] apply parametric-based learning approaches, i.e., Locally Linear Embedding (LLE) and sparse representation kernel functions, respectively, to model the

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patch-based correlations between the low- and high-resolution images, and thus better preserve the local detailed texture and individual facial features of the input image. In contrast to such parametric-based methods, the local Markov Random Field (MRF)-based models proposed in [14,29] perform the synthesis process using only those pairwise examples in the training set which have the greatest degree of similarity to the unknown input image. Consequently, the detailed texture of the input image is more faithfully reproduced in the synthesized output image. However, for both parametric and non-parametric face hallucination methods, several important issues must be considered. First, the synthesis targets (i.e., the human face) have a common structural geometry, and hence both the global and the local facial properties of the synthesized results must be preserved. Second, the synthesized results are highly sensitive to inconsistencies between the appearances of the training images and testing images, respectively, and hence a robust mapping between the low-resolution and high-resolution pairwise samples in the training dataset must be obtained.

This study proposes a novel learning-based face hallucination system based on a two-dimensional direct combined model (2DDCM) approach. The proposed system takes into account both the local details of the facial features and the global geometry structure of the face during the training and synthesis procedures. Unlike most existing parametric-based approaches, which have the ability to synthesize facial images which are similar to the training images, but perform less well for test images which do not resemble the original training samples; the 2DDCM framework proposed in this study not only provides the ability to retain the distinctive personal features of the input image given even a limited number of training samples, but also provides the means to synthesize high-resolution facial images with poses and expressions which do not appear within the original training set.

1.1. Related works

The face hallucination method proposed in this study utilizes an example-based learning approach. Most example-based methods require multiple pairwise examples of the high-resolution and low-resolution images as prior knowledge, and treat the two image sets as two related but different classes. Learning algorithms, such as Principal Component Analysis (PCA) or Canonical Correlation Analysis (CCA), are then applied to analyze the correlations between the two classes in specified feature subspaces. Finally, the learned relationship between the two classes is used to derive a mapping function (or regression matrix) between the low-resolution input images and the high-resolution output images. Consider a dataset with the structure $\{I^X{}_i, I^Y{}_i\}_i^P$, in which I_i^X is the low-resolution image of the i'th training pairwise sample, I_i^Y is the corresponding high-resolution image, and P is the number of (I^X, I^Y) training facial pairs in the database. Based on the definition given in [18], existing example-based approaches for synthesizing a high-resolution image from a low-resolution input image can be

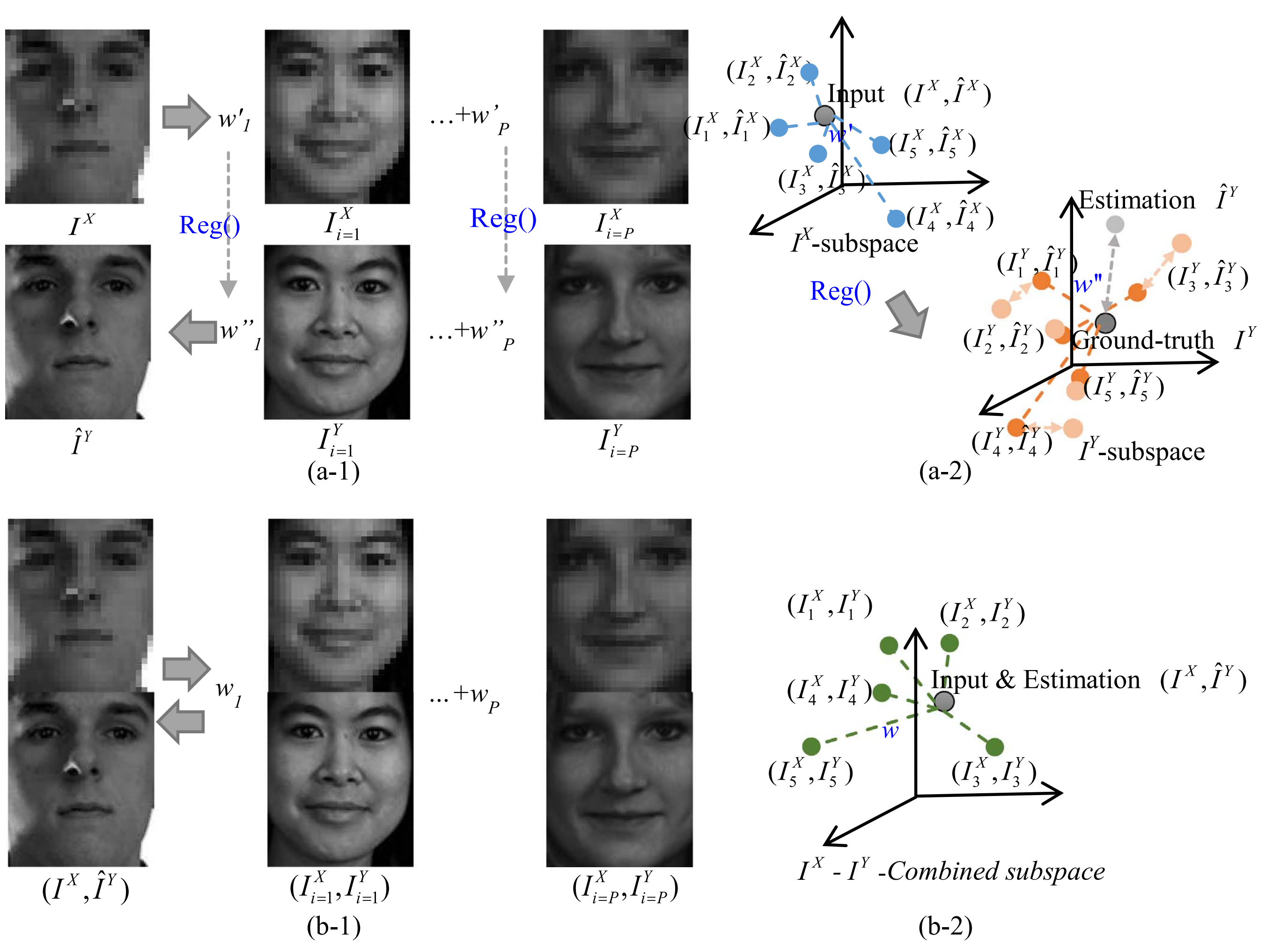

Fig. 1. Comparison of independent-based approach and combination-based approach for face hallucination using pairwise low-resolution and high-resolution facial images. (a-1) Synthesis framework of independent-based approach. (a-2) Schematic illustration of I^X-subspace and I^Y-subspace in (a-1). (b-1) Synthesis framework of combination-based approach. (b-2) Schematic illustration of combined $I^X - I^Y$ subspace in (b-1).

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