Face Hallucination: How Much It Can Improve Face Recognition

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***Abstract*— Face hallucination has been a popular topic in image processing in recent years. Currently the commonly used performance criteria for face hallucination are peak signal noise ratio (PSNR) and the root mean square error (RMSE). Though it is logically believed that hallucinated high-resolution face images should have a better performance in face recognition, we show in this paper that this 'the higher resolution, the higher recognition' assumption is not validated systematically by some designed experiments. First, we illustrate this assumption only works when the image solution is sufficiently large. Second, in the case of very extreme low resolutions, the recognition performance of the hallucinated images obtained by some typical existing face hallucination approaches will not improve. Finally, the relationship of the popular evaluation methods in face hallucination, PSNR and RMSE, with the recognition performance are investigated. The findings of this paper can help people design new hallucination approaches with an aim of improving face recognition performance with specified classifiers.**

I. INTRODUCTION

Research on face recognition has been popular for over a decade. In general, face recognition system consists of three steps [1]: face detection, feature extraction and face recognition. Face detection techniques have been widely applied in our daily lives, such as the face detection function in digital cameras. In terms of feature extraction and face recognition, many approaches have been proposed such as Principal Component Analysis (PCA) [2], Linear Discriminant Analysis (LDA) [3], Locality Preserving Projections (LPP) [4] and Face Recognition via Sparse Representation (SRC) [5]. Face recognition algorithms are also widely implemented nowadays, for example, the face recognition function in *facebook* and *iphoto*.

In surveillance systems, when faces are captured in a far distance, their images are generally regarded too small to be recognized. In order to enhance the face recognition performance for a far distance surveillance system, people think face enhancement is required and thus face hallucination technique is proposed with such motivation. Face hallucination aims to infer additional pixels to increase the resolution of face images in order to improve the performance of automatic face recognition for very low-resolution face images. As to face hallucination, Baker and Kanade [6], [7] was the first to introduce the face hallucination theory. Based on the image super-resolution theory, they proposed a learning based algorithm, which learns the prior on the spatial distribution of the face image gradient and yields high-resolution face images. Numerous face hallucination approaches have been proposed ever since [8], [9], [10], [11], [12], [13], [14], [15], [16]. For example, Wang and Tang proposed an efficient hallucinating algorithm [8]. They treated the low-resolution and high-resolution faces as two groups, and tried to find the linear transformation relation between those two groups. They derived this through Principal Component Analysis (PCA), where both the low and high resolution images are projected into their eigen-subspaces, and the linear transformation could be interpreted in these two subspaces. A statistical modeling approach was proposed by Liu $et\ al.$ [9], who solved the enhancement problem through two steps. The global features and local features were separately derived from a global parametric model and a local non-parametric model. A hallucinated human face can be derived by combining the global and local features. Based on their work, Zhuang $et\ al.$ adopted Locality Preserve Projection (LPP) and Radial Basis Function (RBF) to produce the global faces and simplify the non-parametric model to generate the local features [10]. Yang $et\ al.$ adopted the Non-negative Matrix Factorization (NMF) algorithm to generate global faces and found the local residues through sparse representation method [11]. Zhang and Cham proposed an approach in frequency domain [12]. They transformed faces through the Discrete Cosine Transformation (DCT), and estimated the high-resolution DC components and AC components separately. Through the inverse DCT, hallucinated faces can be produced. Other super-resolution approaches for generic images also can be used in face hallucination. Chang $et\ al.$ proposed a super-resolution approach based on the Locality Linear Embedding [13]. Yang $et\ al.$ proposed a Sparse Representation super-resolution approach [14]. Both of them can generate smooth hallucinated faces efficiently and with good Peak Signal Noise Ratio (PSNR) or Root Mean Square Error (RMSE) performance.

As one original motivation of face hallucination is to improve face recognition performance. However, many of the previous hallucinating approaches only used the PSNR or RMSE values to evaluate the hallucinating quality instead of evaluating the recognition performance. Moreover, they did not prove the robustness of their algorithms on images with extremely very low-resolutions, where face hallucination is actually most needed. This paper aims to fill these gaps by studying the relationships among image resolution, recognition performance and hallucination performance. We

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have three contributions in this paper. First, through extensive experiments we prove that in case of extremely very low-resolution, the effectiveness of hallucinating on improving face recognition is actually debatable. Second, we reveal that the recognition performance can be improved if the image resolution is large enough. Finally, by studying the relationship between the recognition rate with PSNR and RMSE values, it has been found that these two commonly used evaluation metrics for hallucination algorithms are not able to accurately reflect how much hallucination could assist in face recognition.

The remaining paper is organized as follows. In section two, we will investigate the relationship of image resolution and recognition performance. In section 3, the face hallucination and recognition are investigated. The Hallucination metrics are discussed in terms of recognition performance. The conclusions are presented in section 5.

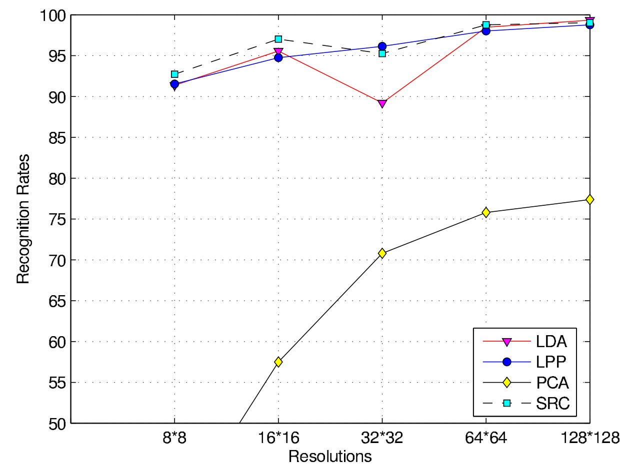


Fig. 2. Recognition Rates in terms of Different Recognition Algorithms.

II. Relationship between Resolution and Recognition

Since one of the the most important aims of face hallucination is to assist in recognition, it is an important issue to determine what kind of face images cannot be recognized by human perceptions or machines. For human perceptions, faces are able to be recognized in reasonably high-resolution images since there are more details available in those images. When the image resolution decreases to a certain threshold, faces are difficult to be recognized by eyes. Fig 1 demonstrates a set of faces from high-resolution 128×128 to very low-resolution 8×8. We can see that the faces become hardly recognizable when the resolution is below 32×32.

With machine recognition, things are surprisingly different. Experiments are conducted on the extended YaleB database [17], where face images are down-sampled from high-resolution (128×128) to a set of low-resolution images: 64×64, 32×32, 16×16 and 8×8. Face recognitions are then performed on images in different resolutions. In all the recognition experiments, half of the images in each class are randomly selected as training data and the remaining half as testing data. Recognition experiments are repeated twenty times for each class and the recognition rate is taken as the averaged value.

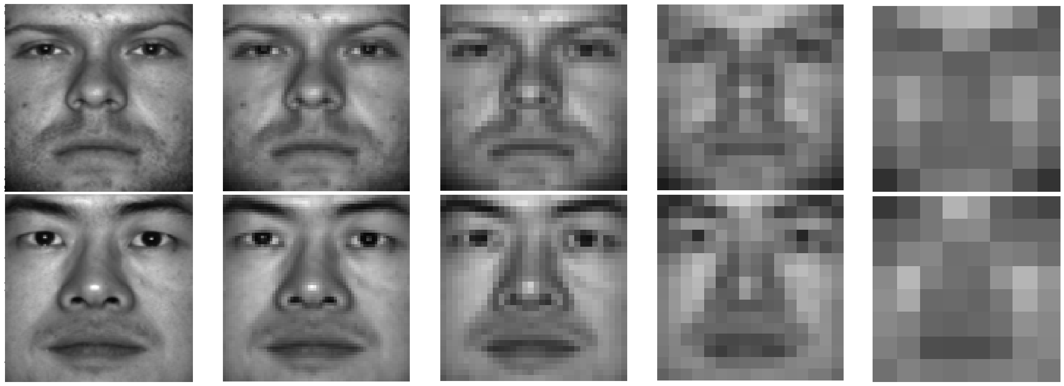
If the resolutions are set as the variable, it is found that when the resolutions vary from 8×8 to 128×128, the recognition rates have different trends in terms of different recognition approaches. Fig 2 shows the results of our experiments in which we recognize faces using different recognition approaches in the Extended YaleB database. We implemented LDA, LPP, PCA and SRC for images with resolutions of 8×8, 16×16, 32×32, 64×64 and 128×128. Recognition by the PCA algorithm has an obvious trend, where the recognition rate increases when face resolution increases. However, the overall recognition rates by PCA is not good enough, ranging from 37.54 to 77.37. LDA, LPP and SRC produce satisfactory recognition rates. It can be seen that in the low resolution, SRC has a very good performance. Specifically in the resolution of 16×16, SRC produces a similar recognition rate as in the highest resolution of 128×128. In the resolution of 32×32, recognition rates drop for both the SRC and LDA methods. The same experiment is also performed in the AR database [18], where the trend of recognition rate varies but still does not increase along with resolution.

From this experiment, it has been shown that though it is not always the case that higher resolutions leads to the higher recognition rates, the recognition performance is in general becoming better with increasing high resolution. Resolution is not the only factor that influences the face recognition performances. There might be some other factors that affect the recognition rate, such as recognition algorithms, types of cameras and different face databases which include illumination, poses, expressions, gender and human races. It can be concluded that the increased resolution does improve the recognition rate in general.

It is worth to point out that the high performances with different classifiers are possibly due to the face database patterns. Also the low resolution images are obtained only from down sampling technique and some innate features of its high resolution images are inherited. It is more interesting to see the recognition performance for hallucinated images by using different approaches. We will investigate this issue in next section.

III. How Far is Face Hallucination from Recognition

The previous section has shown that face high resolution does not guarantee the improvement of face recognition. In order to clearly evaluate the performance of face hallucination in recognition context, another experiment is conducted in which we enhance the low-resolution face images through four typical face hallucination approaches: Eigen Transformation (Eigen) [8], Two Step Face Hallucination Theory (TwoStep) [9], Sparse Representation Super Resolution (ScSR) [14] and Cubic Interpolation (Cubic) [19]. The image resolutions are enhanced in three types of resolutions: from



(a) 128×128 (b) 64×64 (c) 32×32 (d) 16×16 (e) 8×8

Fig. 1. Face Image Display in terms of Different Resolutions.

8×8 to 32×32, from 16×16 to 64×64 and from 32×32 to 128×128. We treat each low-resolution image in the Extended YaleB and AR databases as a test image, and use the FRGC [20] face database as the training data of the hallucination experiment. As a result a set of hallucinated high-resolution faces are derived. In the recognition experiment, the testing faces are randomly selected from the hallucinated faces and the training data are randomly selected from the original high-resolution images. LDA [3], LPP [4], PCA [2] and SRC [5] face recognition algorithms are adopted. Similarly, the recognition experiment is repeated twenty times and the recognition rates are averaged from them.

The recognition rates of the low-resolution faces, hallucinated faces and high-resolution faces are compared in terms of different face recognition approaches. Fig 3 (i) demonstrates the experimental results when the low-resolution is 8×8 and the hallucinated high-resolution is 32. It can be seen that when the image resolutions is extremely very low, hallucinated faces actually do not provide much help to recognition rate. In fact, most hallucinated high-resolution faces have lower recognition rates compared with the low-resolution faces. This gives us a conclusion that when the image resolution is low enough, image hallucination will not help for face recognition. This is very important.

However, the situation is totally different when the images resolution is enhanced from 32×32 to 128×128. Fig 3 (ii) shows the experimental result for such cases. For most hallucinated 128×128 images, face recognition rates increase when compared with the original 32×32 faces using all four typical recognition approaches. This means that if the original face is in the resolution of 32×32, the face recognition rates can be improved, sometimes significantly, by enhancing the image resolutions through hallucinating faces, while in the resolution of 8×8, the recognition performance can hardly be enhanced by these super-resolution approaches.

Similar results have been obtained by performing the same experiment in the AR database [18]. Fig 4 shows the results of our experiment in AR database.

By combining the results by now, we can find that image resolution is not a good indicator for face recognition (here we ignore the noise high dimensional images). If the low resolution images are obtained by down sampling technique, we can follow the principle ”higher resolution and higher recognition performance” in general. If the low resolution images are obtained by hallucination techniques, the threshold of the extremely low resolution case is noted in Section 3. Next, we further investigate this issue through the metrics of hallucination, PSNR and RMSE.

IV. How to Evaluate the Hallucination Results

Most of the existing face hallucination algorithms use the Root Mean Square Error (1) and Peak Signal Noise Ratio (2) to evaluate the enhancement results. They are defined respectively as:

$$RMSE = \sqrt{\frac{\sum_{1}^{m} \sum_{1}^{n} (I - \hat{I})^2}{m \times n}} \tag{1}$$

$$PSNR = 20 \cdot \log_{10} \frac{255}{RMSE} \tag{2}$$

where m and n are the numbers of rows and columns of the high-resolution images. I and $\hat{I}$ represent the original high-resolution testing images and hallucinated high-resolution images respectively.

However, both of these two parameters only measure the holistic differences between the original low-resolution images and hallucinated high-resolution images, which cannot count the correctness pixel by pixel. We aim to verify whether high PSNR or RMSE values mean good hallucination in terms of recognition performance. An experiment is conducted to enhance the face resolution from 32×32 to 128×128, and compares the PSNR and RMSE values with recognition rates in the LDA, LPP, PCA and SRC. The comparison is shown in table I, where the best super-resolution result appears at the ScSR approach in terms of the PSNR and RMSE evaluation. However, in PCA recognition method the best recognition rate appears at the TwoStep approach and in SRC recognition method the best

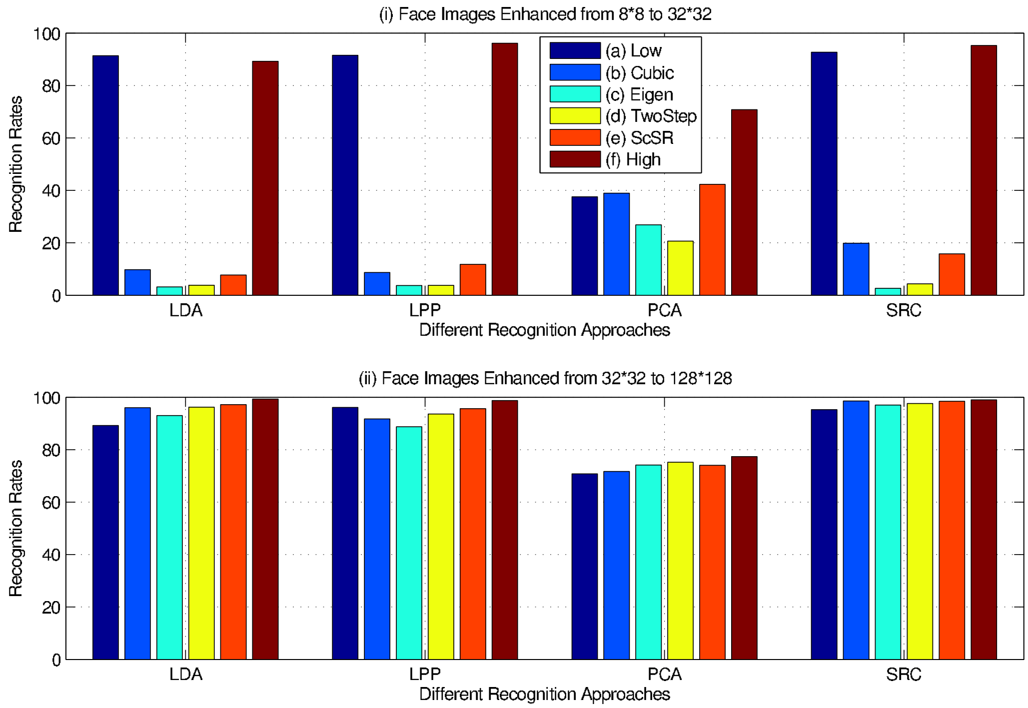


Fig. 3. Recognition Rates of Hallucinated Faces in YaleB database. (a) Recognition Rate of Low Resolution Faces. From (b) to (e) are Recognition Rates of High Resolution Faces Hallucinated through Cubic Interpolation [19], Eigen-Transformation [8], Two Step Hallucinating Theory [9] and Sparse Representation Super-Resolution [14]. (f) Recognition Rate of Original High Resolution Faces.

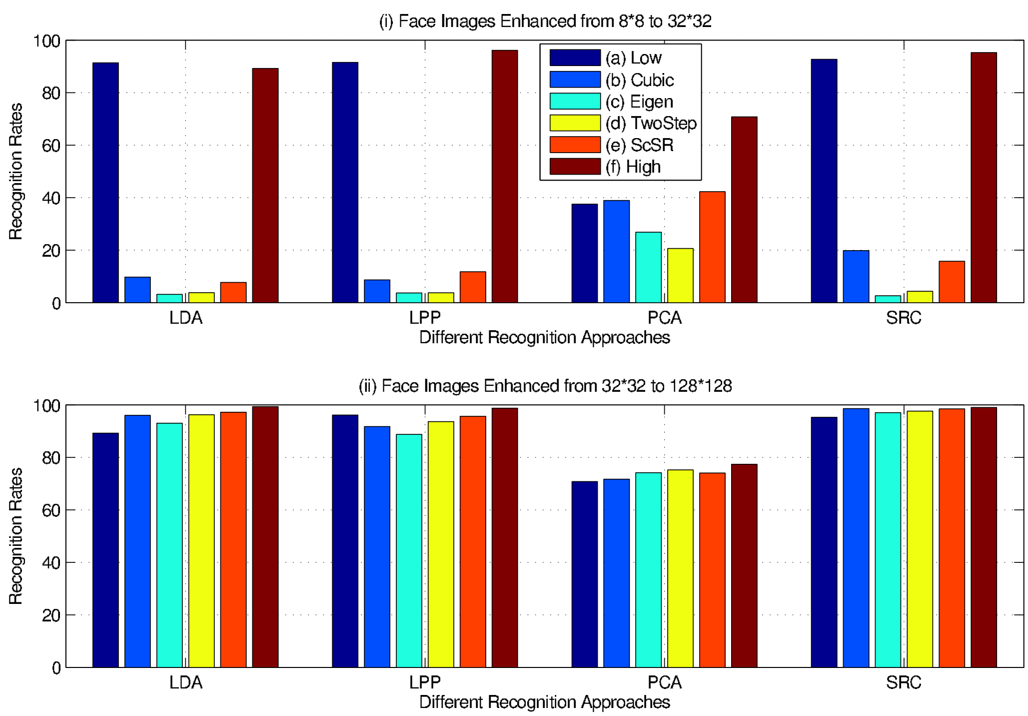


Fig. 4. Recognition Rates of Hallucinated Faces in AR database. (a) Recognition Rate of Low Resolution Faces. From (b) to (e) are Recognition Rates of High Resolution Faces Hallucinated through Cubic Interpolation [19], Eigen-Transformation [8], Two Step Hallucinating Theory [9] and Sparse Representation Super-Resolution [14]. (f) Recognition Rate of Original High Resolution Faces.

TABLE I
COMPARISON BETWEEN RECOGNITION RATES AND PSNR/RMSE VALUES.

	ScSR	TwoStep	Eigen	Cubic
LDA	97.21	96.23	93.03	96.01
LPP	95.63	93.61	88.77	91.75
PCA	74.07	75.22	74.17	71.71
SRC	98.48	97.63	97.02	98.60
$PSNR$	31.52	27.57	22.48	30.96
$RMSE$	7.04	11.15	20.65	7.51

TABLE II
COMPARISON BETWEEN RECOGNITION RATES AND PSNR/RMSE VALUES WHEN HALLUCINATING FACES FROM 8×8 TO 32×32.

	ScSR	TwoStep	Eigen	Cubic
LDA	7.74	3.82	3.20	9.91
LPP	11.81	3.77	3.73	9.93
PCA	42.30	20.66	26.84	37.98
SRC	12.87	4.34	3.60	19.18
$PSNR$	22.76	13.00	12.01	22.25
$RMSE$	19.40	58.99	64.00	20.61

recognition rate appears at the Cubic approach. In PCA recognition method, Cubic interpolation approach performs the worst in recognition rate while it performs better than Eigen-transformation and Two-step approaches in terms of PSNR and RMSE. The experiment clearly shows that neither PSNR nor RMSE could provide a good evaluation for the performance of hallucination algorithms in terms of assisting face recognition.

Similar experiment is conducted to enhance the face resolution from 8×8 to 32×32, and compares the PSNR and RMSE values with recognition rates in the LDA, LPP, PCA and SRC. The comparison is shown in table II, where the best super-resolution result appears at the PCA approach in terms of the PSNR and RMSE evaluation.

If we look the table I and table II further, we can find the best performance classifiers in two cases are different, SRC in table I and PCA in table II. With better classifier selected, its performance is increasing with better PSNR values for different hallucinated images. This is coincident with our logical reasoning and motivates us to develop hallucinated techniques with selected classifiers. If we look these two tables with figure 3 together, we will find that it is unnecessary to hallucinate face images if the resolution is extremely low (8x8 in our case) as the hallucinated images will not improve the recognition performance in this case as seen in Fig 3 (i).

V. CONCLUSION

One of the main purpose of face hallucination techniques is to help enhance the face recognition performance by both human perception and machines. Through extensive experiments in this paper, we found that when the face image resolution is below 32×32, they can hardly be recognized by human perception, but can still be well recognized by machines if such resolution is obtained by down sampling, through some recognition algorithms such as LDA, LPP and SRC. It is also found that resolutions are not the only factor that influences face recognition rate. Higher resolution does not necessarily mean higher recognition rate for all classifiers in general. Many other factors may affect the performance of face recognition.

Four typical face hallucination approaches [8], [9], [14], [19] are implemented to enhance the low-resolution face images to high-resolution: from 8×8 to 32×32, from 16×16 to 64×64 and from 32×32 to 128×128. Face recognitions are then performed on those hallucinated face images using four popular face recognition algorithms: LDA, LPP, PCA and SRC (ref.). From our experiments, when the face images is enhanced from 32×32 to 128×128, the hallucinated high-resolution face images can be better recognized than the low-resolution images. However, in extremely very low dimension (8×8), some of the face hallucination approaches do not work properly. Recognition rates on the hallucinated faces could be even lower than those on the original low-resolution face images.

PSNR and RMSE are the common evaluation metrics for face hallucination results. We compared PSNR and RMSE values of hallucinated faces with recognition rates. The comparison shows that in some circumstances, PSNR and RMSE values are not able to exactly reflect the hallucinating performance in terms of assisting recognition.

The results in this paper will give us a revelation for improving face recognition performance with low resolution images. First, we need to select a classifier and then explore the resolution threshold from which the performance of the hallucinated images can be improved. Finally, we select a best hallucinated techniques in terms of PSNR.

More factors are to be considered to develop a robust and effective face hallucination algorithm in future so that it could effectively help enhance face recognition with a selected classifier. More effective evaluation metrics that can directly connect the hallucination quality and the recognition correctness are required in our future study.

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