CHAPTER IV

THE EXPERIMENTAL RESULTS

4.1 Image Databases

We used face images from a subset of FERET databases to form two data sets for training and testing images in four color models, which are RGB, YCbCr, HSV and CIELAB. The experiments are conducted with a large number of face images from FERET data set [78,79] and other collections, which consist of many different races, illuminations and types of face images.

4.1.1 FERET Database

The FERET database [78,79] contains 1199 individuals and 365 duplicate sets of images. There are images per subject, one for each of the following facial expressions or configurations: centerlight, with glasses, happy, left-light, without glasses, normal, right-light, sad, sleepy, surprised, and wink. All sample images of one person from the FERET database are shown in Fig. 4.3.

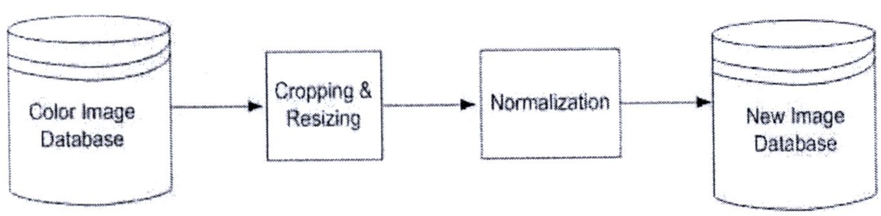

Figure 4.1 Preprocessing diagram

4.2 Preprocessing

In some databases, we notice that the background, some possible transformations of the object (scaling, rotation and translation) and sensor-dependent variations (for example, automatic gain control calibration and bad lens points) could undermine the face hallucination performance. This impact can be minimized by cropping and normalization. The preprocessing of this dissertation is following to the diagram in Fig. 4.1.

Figure 4.2 Cropping image

4.2.1 Cropping and Resizing

In this dissertation, the cropping procedure was manually implemented by human. Each image was manually cropped and resized to 30 $\times$ 30 pixels. By attempting to align images such that the faces are the same size, in the same position and at the same orientation. Specifically, the image is scaled and translated to make the eye coordinates coincident with pre-specified locations in the output. After cropping, all of the images were resized to same dimensions by linear interpolation. The cropping for a sample image on FERET database was shown in Fig. 4.2.

Figure 4.3 Example training faces from FERET database in our proposed algorithm

4.2.2 Normalization

The normalization is to compensate for intensity variations. By

$$\mathbf{A}' = \frac{\mathbf{A}}{||vec(\mathbf{A})||} \tag{4.1}$$

where $\mathbf{A}$ is the original image matrix, $\mathbf{A}'$ is the normalized image matrix and $||vec(\mathbf{A})||$ represents to the norm of the vectorization of the image matrix.

4.3 Experiments and Analysis on Color Face hallucination with TensorPCA subspace

In this section, we experimentally evaluate our proposed technique by using TensorPCA methods. In our experiments, we randomly select 500 normal expression images of different persons on the same light condition and other 50 images are used for testing. According to demand, we manually crop the interesting region of the faces and unify the images to the size of (30 × 30).

In the degradation process, each testing image (LR) is introduced with Gaussian blur with variance 1 and resized by down-sampling 2:1 (15 × 15), then we add Gaussian noise with variance 10^{-6}. To establish a standard training data set, we aligned these face images manually by hand, marking the location of 3 points: the centers of the eyeballs and the lower tip of the nose. These 3 points define an affine warp, which is used to warp the images into a canonical form. We use Peak signal-to-noise ratio (PSNR) to evaluate the performance of the facial reconstruction.

We compare the hallucination results between the traditional PCA and tensorPCA by vary both of the number of principal component from 90 to 100 percent PCA. The experimental results are shown in Fig. 4.4-4.7: (a) original HR images (30×30), (b) input LR images (15×15) with noise, motion and blur in LR images, (c)-(e) face hallucination result with 90, 95 and 100 percent traditional PCA respectively, (f)-(h) face hallucination result with 90, 95 and 100 percent tensorPCA respectively.

From the traditional PCA method, the color face image has to be converted to a vector representation. Then, we can see that from the hallucinated results in Fig. 4.4-4.7 (c)-(e), it can hardly maintain global smoothness and visual rationality, especially on location around color face contour and margin of the nose and the mouth. In addition, the results have some noise around the eyes and mouth. On the other hand, the hallucinated results from the tensorPCA method in Fig. 4.4-4.7 (f)-(h) can reconstruct the reasonable color face images which are compared with the ground truth color face images in Fig. 4.4-4.7 (a). In Fig. 4.4-4.7, the outcomes we get in HSV color space show that the color distort from the original HR images. Additionally, the details in our hallucination results such as eyes, noses, lips and eyebrows quite differ from the original HR images.

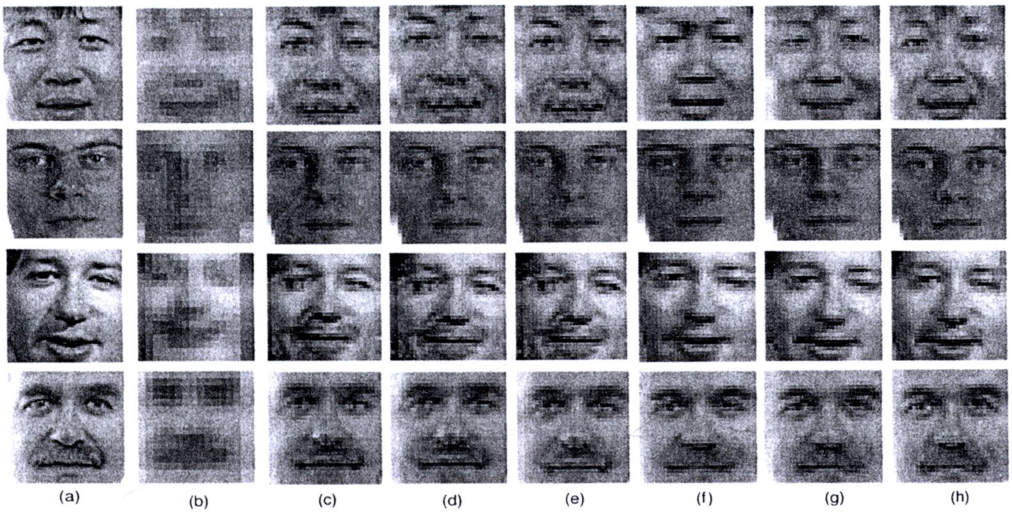

Figure 4.4: Color hallucinated face images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent tensorPCA; (g) face hallucination result with 95 percent tensorPCA; (h) face hallucination result with 100 percent tensorPCA;

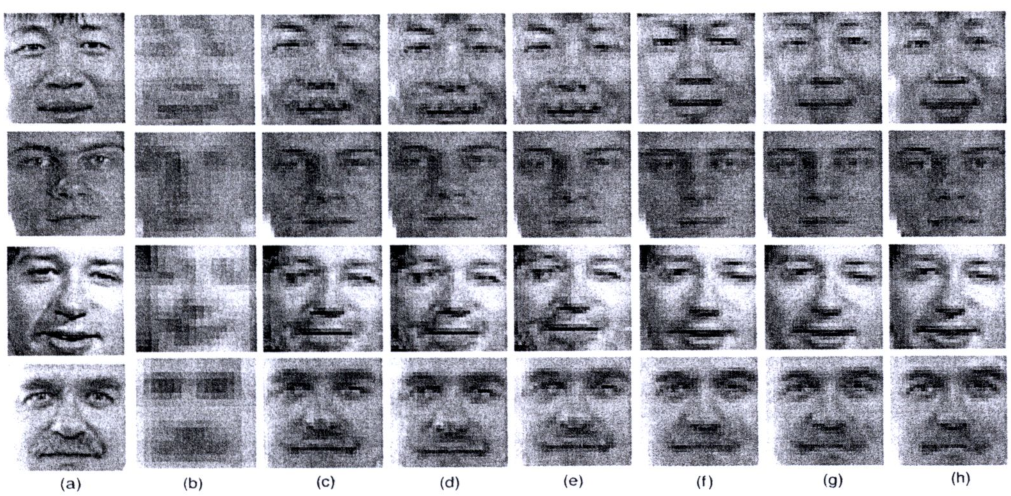

Figure 4.5: Color hallucinated face images in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent tensorPCA; (g) face hallucination result with 95 percent tensorPCA; (h) face hallucination result with 100 percent tensorPCA;

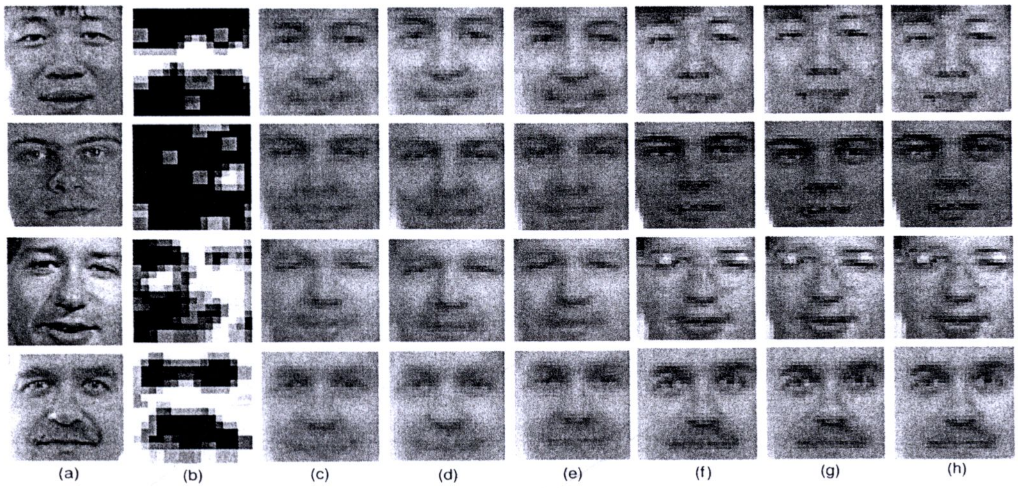

Figure 4.6: Color hallucinated face images in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent tensorPCA; (g) face hallucination result with 95 percent tensorPCA; (h) face hallucination result with 100 percent tensorPCA;

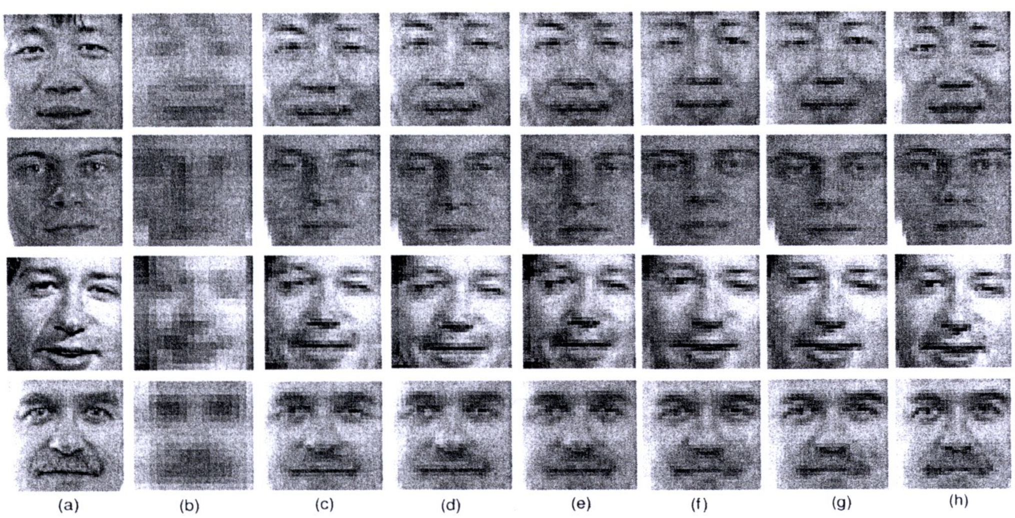

Figure 4.7: Color hallucinated face images in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent tensorPCA; (g) face hallucination result with 95 percent tensorPCA; (h) face hallucination result with 100 percent tensorPCA;

Table 4.1: PSNR results of the facial images with traditional PCA and tensorPCA methods in Fig. 4.4 for RGB color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	24.05 dB	30.13 dB	23.40 dB	23.98 dB
2) 95 $percent\ PCA$	24.13 dB	30.39 dB	23.77 dB	24.09 dB
3) 100 $percent\ PCA$	24.34 dB	30.67 dB	23.98 dB	24.32 dB
4) 90 $percent\ tensorPCA$	26.63 dB	35.63 dB	27.61 dB	29.88 dB
5) 95 $percent\ tensorPCA$	30.96 dB	36.69 dB	28.33 dB	30.60 dB
6) 100 $percent\ tensorPCA$	31.18 dB	40.04 dB	28.61 dB	30.82 dB

Table 4.2: PSNR results of the facial images with traditional PCA and tensorPCA methods in Fig. 4.5 for YCbCr color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	24.13 dB	30.21 dB	23.61 dB	24.07 dB
2) 95 $percent\ PCA$	24.25 dB	30.51 dB	23.98 dB	24.22 dB
3) 100 $percent\ PCA$	24.58 dB	30.88 dB	24.22 dB	24.64 dB
4) 90 $percent\ tensorPCA$	26.71 dB	36.08 dB	27.67 dB	30.09 dB
5) 95 $percent\ tensorPCA$	30.98 dB	36.87 dB	28.45 dB	30.58 dB
6) 100 $percent\ tensorPCA$	31.32 dB	40.13 dB	28.64 dB	30.78 dB

Table 4.3: PSNR results of the facial images with traditional PCA and tensorPCA methods in Fig. 4.6 for HSV color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	22.86 dB	26.85 dB	22.51 dB	22.77 dB
2) 95 $percent\ PCA$	23.02 dB	27.04 dB	22.87 dB	22.91 dB
3) 100 $percent\ PCA$	23.24 dB	27.63 dB	23.06 dB	23.12 dB
4) 90 $percent\ tensorPCA$	26.58 dB	30.91 dB	27.60 dB	29.34 dB
5) 95 $percent\ tensorPCA$	27.19 dB	31.05 dB	27.79 dB	29.51 dB
6) 100 $percent\ tensorPCA$	27.58 dB	31.12 dB	27.85 dB	29.60 dB

Table 4.4: PSNR results of the facial images with traditional PCA and tensorPCA methods in Fig. 4.7 for CIELAB color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	24.42 dB	30.66 dB	23.82 dB	24.13 dB
2) 95 $percent\ PCA$	24.67 dB	31.03 dB	24.01 dB	24.36 dB
3) 100 $percent\ PCA$	24.93 dB	31.78 dB	24.34 dB	24.79 dB
4) 90 $percent\ tensorPCA$	29.48 dB	36.41 dB	27.90 dB	30.45 dB
5) 95 $percent\ tensorPCA$	31.54 dB	37.03 dB	28.28 dB	31.42 dB
6) 100 $percent\ tensorPCA$	31.97 dB	40.29 dB	28.60 dB	31.63 dB

In Table. 4.1-4.4, we show the PSNR results from the hallucinated images in Fig. 4.4-4.7. We can see that the hallucination method with tensorPCA has more PSNR values compared with the traditional PCA method. In RGB color model, at the same percentage of eigenvalues 90, 95 and 100, tensorPCA method can give more higher the PSNR values than the traditional PCA about 2.58-5.90 dB, 4.56-6.83 dB and 4.63-9.37 dB respectively. However, in HSV color space the PSNR results in Table. 4.1-4.4, the tensor PCA method can also give more higher the PSNR values than the traditional PCA about 3.72-6.57 dB, 4.01-6.60 dB and 3.49-6.48 dB at the same percentage of eigenvalues 90, 95 and 100 respectively. Moreover, the PSNR results in CIELAB color space are the best performance among color spaces.

4.4 Experiments and Analysis on Color Face hallucination with Linear Regression Model in MPCA

In this experiment, the MPCA is used to perform principal component analysis of the training images and we investigate the performance of our proposed method in sense of impact of number of eigenvalues, impact of training set size, robustness to noise and complexity respectively.

4.4.1 Impact of Number of Eigenvalues

The MPCA is used to perform principal component analysis of the training images. Some sample results which compared between the tensorPCA and MPCA are shown in Fig. 4.8-4.11. The figures are organized as followed: column (a) the original HR (30×30) color images; (b) input the LR color images (15×15) with noise, motion and blur; (c)-(e) face hallucination results with Traditional PCA method; (f)-(h) face hallucination results with linear regression model in MPCA and the number of eigenvalue is varied from 90 to 100 percent. Compared with the input image and the traditional PCA method result, the hallucinated face images from the linear regression model in MPCA have much clearer detail features. As shown in Fig. 4.8-4.11 (c), (d) and (e), with traditional PCA method, we can observe that dirty disturbance in the global reconstructed images and the results have some noise around the eyes and mouth. In addition, all the PSNR results in different both color space and the number of PCA are shown in Table. 4.5-4.8. As we can see, the PSNR values from the MPCA method are significantly higher than the traditional PCA method.

Additionally, we compare between the hallucination method with linear regression model in MPCA and other traditional methods such as bilinear interpolation and Liu method [80]. All the results are shown in Fig. 4.12-4.15: (a) the original HR (30×30) color images; (b) input the LR color images (15×15) with noise, motion and blur; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method and (e)-(g) face hallucination results with linear regression model in MPCA and the number of eigenvalue is varied from 90 to 100 percent. We can see that the performance of hallucination by our proposed method is much better. Likewise, the hallucination results from bilinear interpolation method, which are displayed in Fig. 4.12-4.15 (c), cannot reconstruct the facial images because this method is unable to solve noise, motion and blur problems.

Noticed from the figures, the performance of our proposed algorithm depends on the number of the PCA. We can remark from the facial results in Fig. 4.8-4.15 that they tend to produce sharper facial features, clear eyelids and mouth. In particular, if our algorithm is implemented with 100 percent of PCA, the results will become similar to the original HR facial images. The outcomes we get in HSV color space show that the color distort from the original HR images. Additionally, the details in our hallucination results such as eyes, noses, lips and eyebrows quite differ from the original HR images.

We also compare the performance which are shown in Fig. 4.16-4.19 between tensorPCA and MPCA method. Since the the tensorPCA method does not realize the correlation between each color channel in a color system. For this reason, in Table. 4.9-4.12, in each hallucinated facial image from our proposed technique has more the PSNR values than the tensorPCA method about 0.2-0.3 dB. All the PSNR results in different both color space and the number of PCA are shown in Table. 4.9-4.10. We can see that our method has the highest PSNR values compared with other methods on all test faces. The PSNR results in CIELAB color space are the best performance among color spaces. However, in HSV color space the PSNR results in Table. 4.9-4.12 are less favorable than other color spaces.

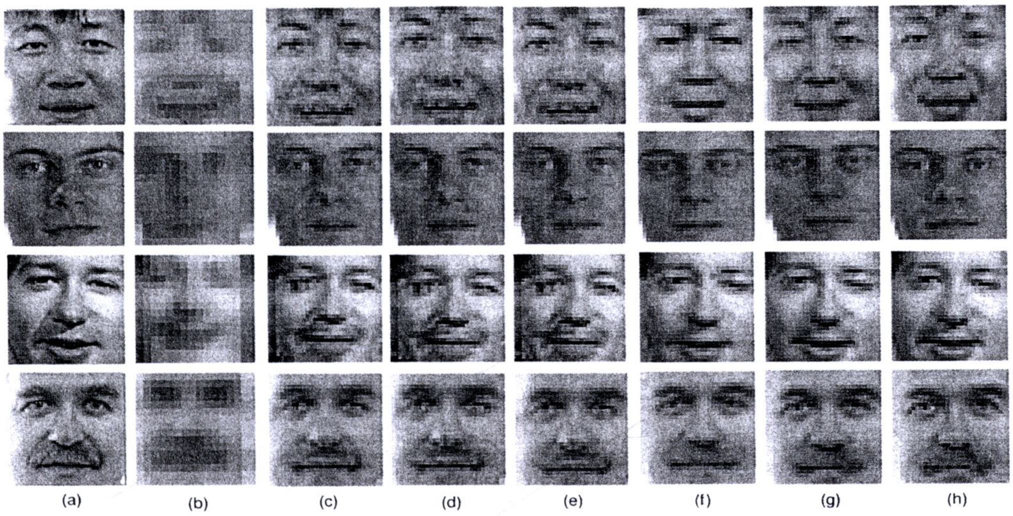

Figure 4.8: Color hallucinated face images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

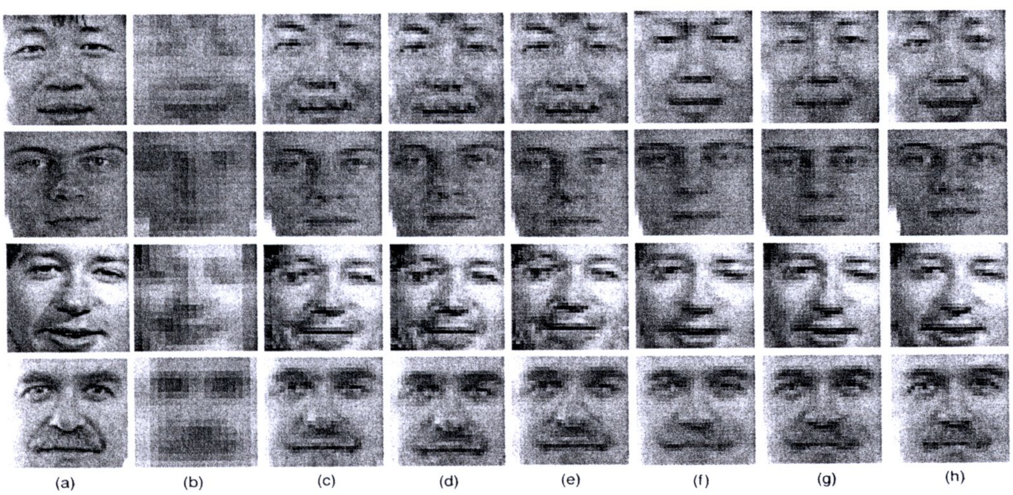

Figure 4.9: Color hallucinated face images in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

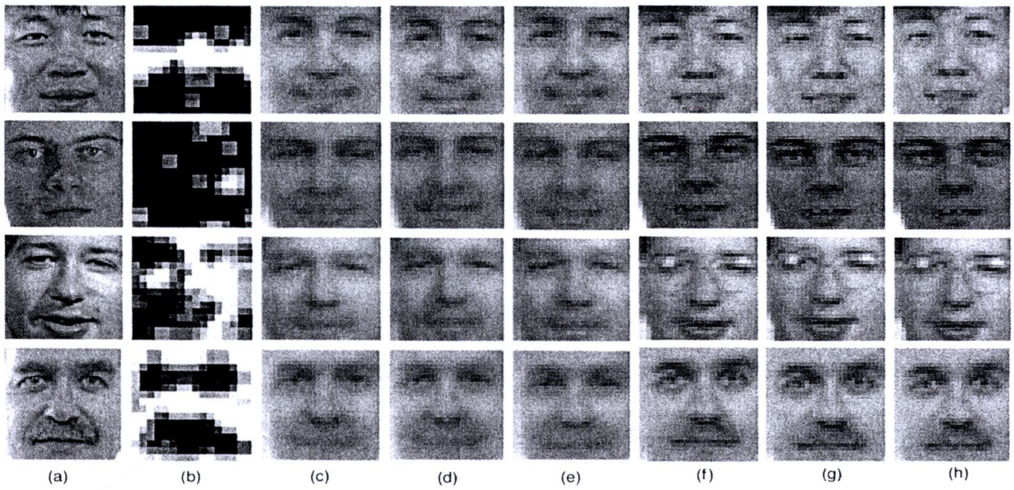

Figure 4.10: Color hallucinated face images in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

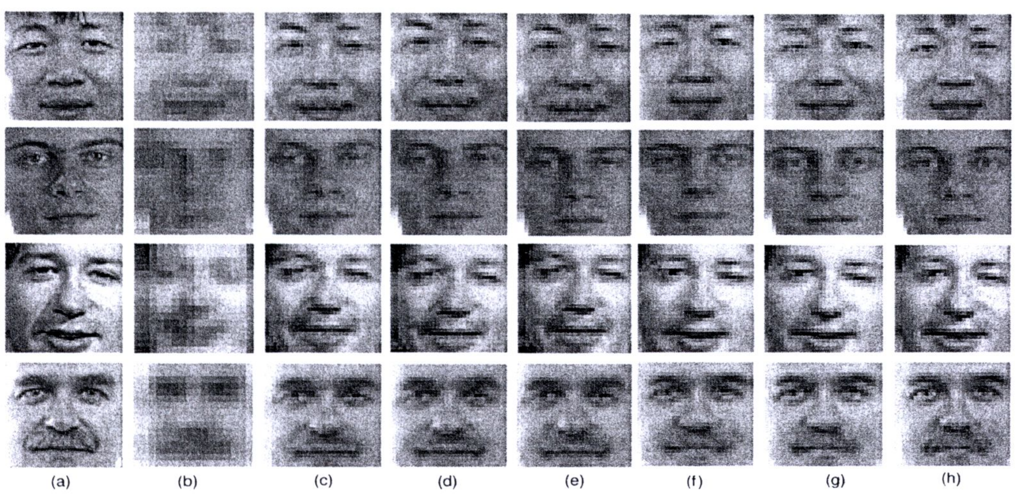

Figure 4.11: Color hallucinated face images in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent traditional PCA; (d) face hallucination result with 95 percent traditional PCA; (e) face hallucination result with 100 percent traditional PCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

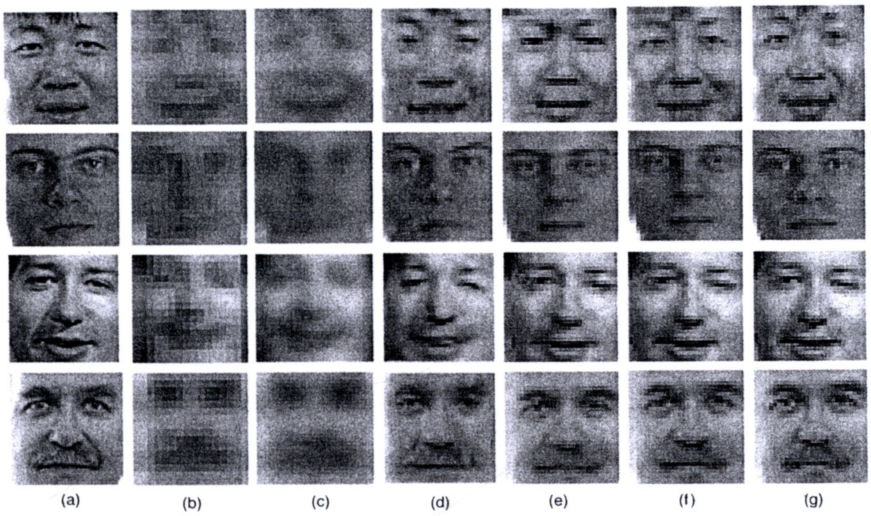

Figure 4.12: Color hallucinated face images, compared with other traditional methods in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA;

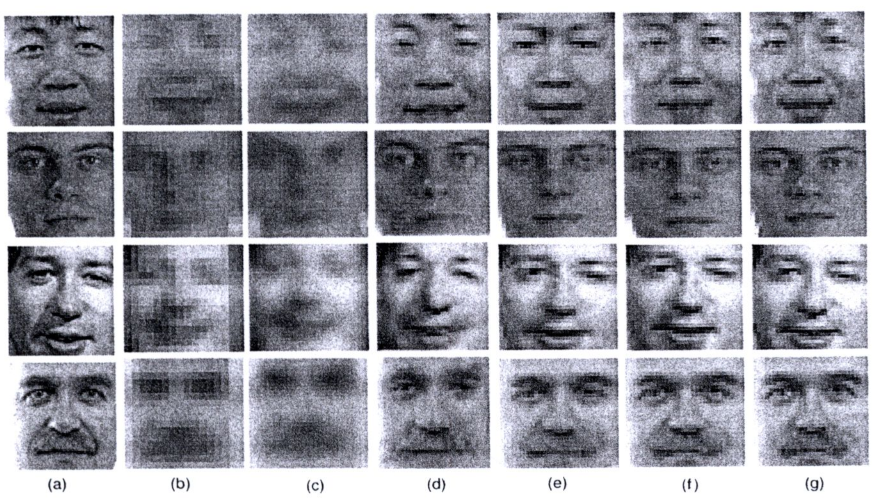

Figure 4.13: Color hallucinated face images, compared with other traditional methods in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA;

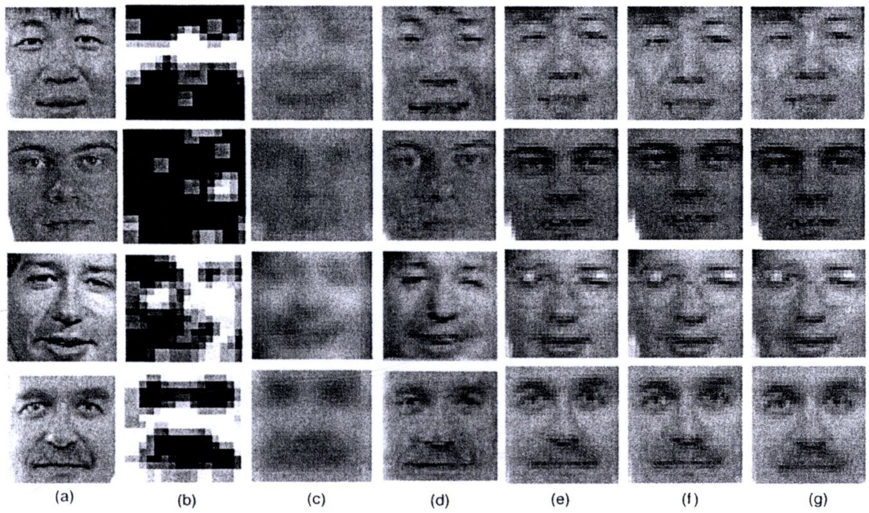

Figure 4.14: Color hallucinated face images, compared with other traditional methods in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA;

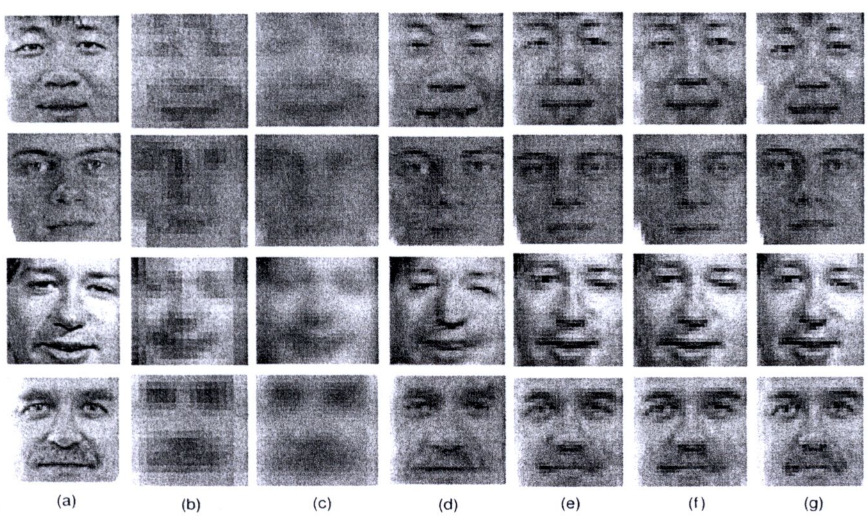

Figure 4.15: Color hallucinated face images, compared with other traditional methods in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA;

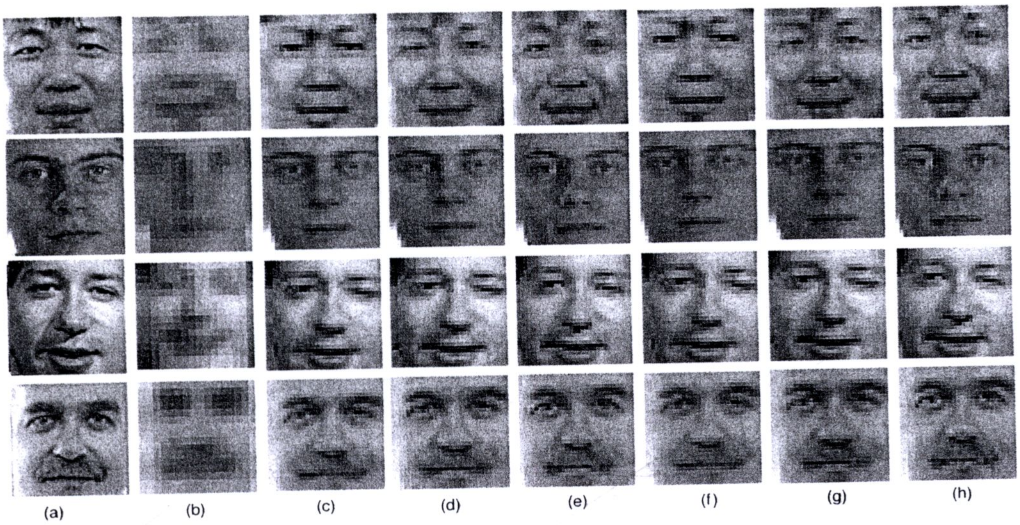

Figure 4.16: Color hallucinated face images, compared between TensorPCA and MPCA in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent tensorPCA; (d) face hallucination result with 95 percent tensorPCA; (e) face hallucination result with 100 percent tensorPCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

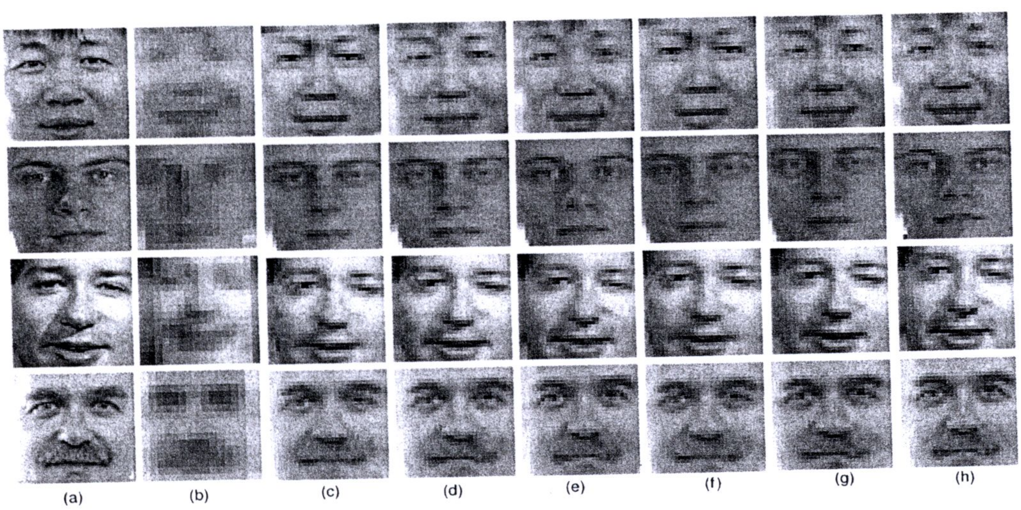

Figure 4.17: Color hallucinated face images, compared between TensorPCA and MPCA in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent tensorPCA; (d) face hallucination result with 95 percent tensorPCA; (e) face hallucination result with 100 percent tensorPCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

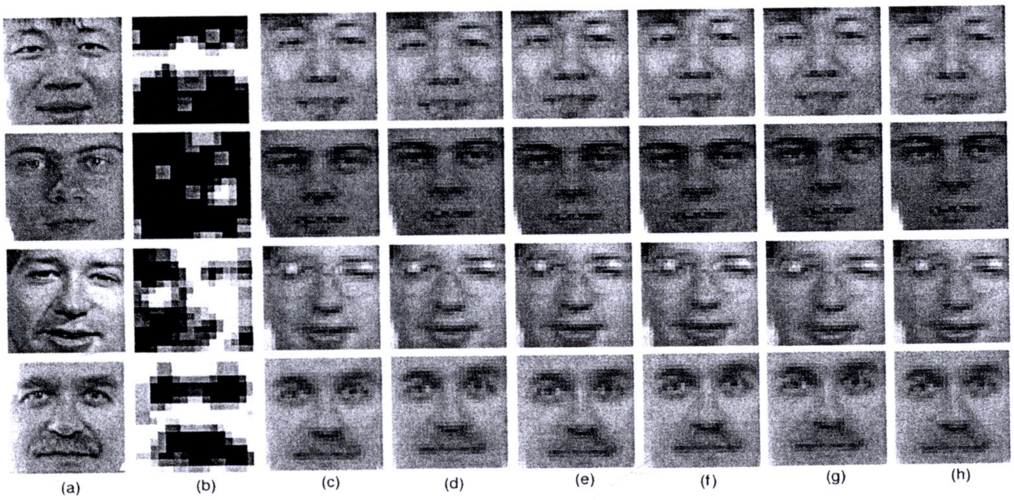

Figure 4.18: Color hallucinated face images, compared between TensorPCA and MPCA in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent tensorPCA; (d) face hallucination result with 95 percent tensorPCA; (e) face hallucination result with 100 percent tensorPCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

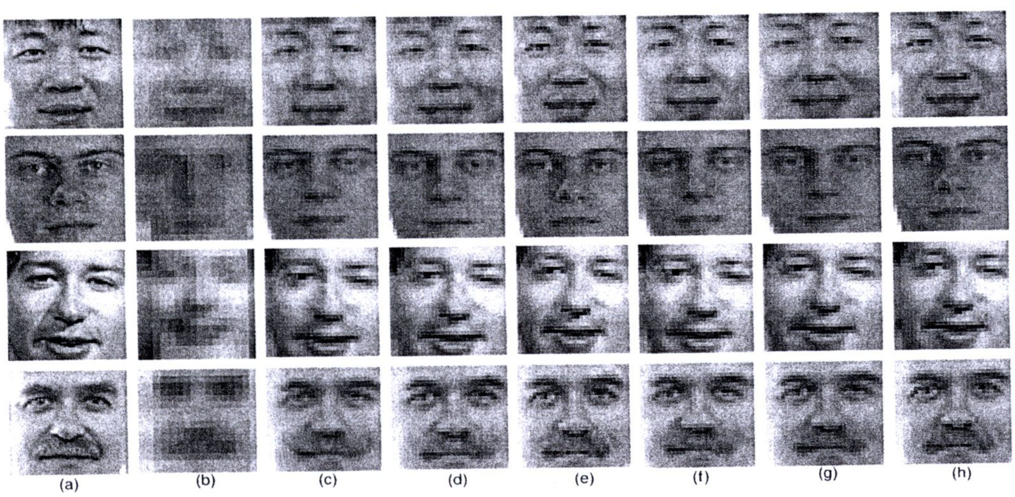

Figure 4.19: Color hallucinated face images, compared between TensorPCA and MPCA in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with 90 percent tensorPCA; (d) face hallucination result with 95 percent tensorPCA; (e) face hallucination result with 100 percent tensorPCA; (f) face hallucination result with 90 percent MPCA; (g) face hallucination result with 95 percent MPCA; (h) face hallucination result with 100 percent MPCA;

Table 4.5: PSNR results of the facial images with traditional PCA and MPCA methods in Fig. 4.8 for RGB color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	24.05 dB	30.13 dB	23.40 dB	23.98 dB
2) 95 $percent\ PCA$	24.13 dB	30.39 dB	23.77 dB	24.09 dB
3) 100 $percent\ PCA$	24.34 dB	30.67 dB	23.98 dB	24.32 dB
4) 90 $percent\ MPCA$	26.88 dB	35.91 dB	27.89 dB	30.14 dB
5) 95 $percent\ MPCA$	31.15 dB	36.91 dB	28.53 dB	30.78 dB
6) 100 $percent\ MPCA$	31.35 dB	40.23 dB	28.74 dB	30.98 dB

Table 4.6: PSNR results of the facial images with traditional PCA and MPCA methods in Fig. 4.9 for YCbCr color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	24.13 dB	30.21 dB	23.61 dB	24.07 dB
2) 95 $percent\ PCA$	24.25 dB	30.51 dB	23.98 dB	24.22 dB
3) 100 $percent\ PCA$	24.58 dB	30.88 dB	24.22 dB	24.64 dB
4) 90 $percent\ MPCA$	27.03 dB	36.38 dB	27.93 dB	30.13 dB
5) 95 $percent\ MPCA$	31.24 dB	37.04 dB	28.57 dB	30.69 dB
6) 100 $percent\ MPCA$	31.47 dB	40.29 dB	28.84 dB	30.88 dB

4.4.2 Impact of training set size

In Fig. 4.20 - 4.22 show examples of hallucinated face images based on a different number of training samples. There is not much difference between the results using 120 and 240 training samples. This shows that our hallucination algorithm can achieve satisfactory results even based on a relatively small training set. However, when the training set is too small, 60 training samples, many individual characteristics cannot be rendered.

Table 4.7: PSNR results of the facial images with traditional PCA and MPCA methods in Fig. 4.10 for HSV color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	22.86 dB	26.85 dB	22.51 dB	22.77 dB
2) 95 $percent\ PCA$	23.02 dB	27.04 dB	22.87 dB	22.91 dB
3) 100 $percent\ PCA$	23.24 dB	27.63 dB	23.06 dB	23.12 dB
4) 90 $percent\ MPCA$	26.85 dB	31.02 dB	27.71 dB	29.41 dB
5) 95 $percent\ MPCA$	27.28 dB	31.18 dB	27.87 dB	29.59 dB
6) 100 $percent\ MPCA$	27.75 dB	31.22 dB	27.96 dB	29.63 dB

Table 4.8: PSNR results of the facial images with traditional PCA and MPCA methods in Fig. 4.11 for CIELAB color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ PCA$	24.42 dB	30.66 dB	23.82 dB	24.13 dB
2) 95 $percent\ PCA$	24.67 dB	31.03 dB	24.01 dB	24.36 dB
3) 100 $percent\ PCA$	24.93 dB	31.78 dB	24.34 dB	24.79 dB
4) 90 $percent\ MPCA$	29.59 dB	36.48 dB	28.01 dB	30.58 dB
5) 95 $percent\ MPCA$	31.66 dB	37.11 dB	28.35 dB	31.52 dB
6) 100 $percent\ MPCA$	32.08 dB	40.35 dB	28.69 dB	31.69 dB

Table 4.9: PSNR results of the facial images with tensorPCA and MPCA methods in Fig. 4.16 for RGB color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ tensorPCA$	26.63 dB	35.63 dB	27.61 dB	29.88 dB
2) 95 $percent\ tensorPCA$	30.96 dB	36.69 dB	28.33 dB	30.60 dB
3) 100 $percent\ tensorPCA$	31.18 dB	40.04 dB	28.61 dB	30.82 dB
4) 90 $percent\ MPCA$	26.88 dB	35.91 dB	27.89 dB	30.14 dB
5) 95 $percent\ MPCA$	31.15 dB	36.91 dB	28.53 dB	30.78 dB
6) 100 $percent\ MPCA$	31.35 dB	40.23 dB	28.74 dB	30.98 dB

Table 4.10: PSNR results of the facial images with tensorPCA and MPCA methods in Fig. 4.17 for YCbCr color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ tensorPCA$	26.71 dB	36.08 dB	27.67 dB	30.09 dB
2) 95 $percent\ tensorPCA$	30.98 dB	36.87 dB	28.45 dB	30.58 dB
3) 100 $percent\ tensorPCA$	31.32 dB	40.13 dB	28.64 dB	30.78 dB
4) 90 $percent\ MPCA$	27.03 dB	36.38 dB	27.93 dB	30.13 dB
5) 95 $percent\ MPCA$	31.24 dB	37.04 dB	28.57 dB	30.69 dB
6) 100 $percent\ MPCA$	31.47 dB	40.29 dB	28.84 dB	30.88 dB

Table 4.11: PSNR results of the facial images with tensorPCA and MPCA methods in Fig. 4.18 for HSV color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ tensorPCA$	26.58 dB	30.91 dB	27.60 dB	29.34 dB
2) 95 $percent\ tensorPCA$	27.19 dB	31.05 dB	27.79 dB	29.51 dB
3) 100 $percent\ tensorPCA$	27.58 dB	31.12 dB	27.85 dB	29.60 dB
4) 90 $percent\ MPCA$	26.85 dB	31.02 dB	27.71 dB	29.41 dB
5) 95 $percent\ MPCA$	27.28 dB	31.18 dB	27.87 dB	29.59 dB
6) 100 $percent\ MPCA$	27.75 dB	31.22 dB	27.96 dB	29.63 dB

Table 4.12: PSNR results of the facial images with tensorPCA and MPCA methods in Fig. 4.19 for CIELAB color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ tensorPCA$	29.48 dB	36.41 dB	27.90 dB	30.45 dB
2) 95 $percent\ tensorPCA$	31.54 dB	37.03 dB	28.28 dB	31.42 dB
3) 100 $percent\ tensorPCA$	31.97 dB	40.29 dB	28.60 dB	31.63 dB
4) 90 $percent\ MPCA$	29.59 dB	36.48 dB	28.01 dB	30.58 dB
5) 95 $percent\ MPCA$	31.66 dB	37.11 dB	28.35 dB	31.52 dB
6) 100 $percent\ MPCA$	32.08 dB	40.35 dB	28.69 dB	31.69 dB

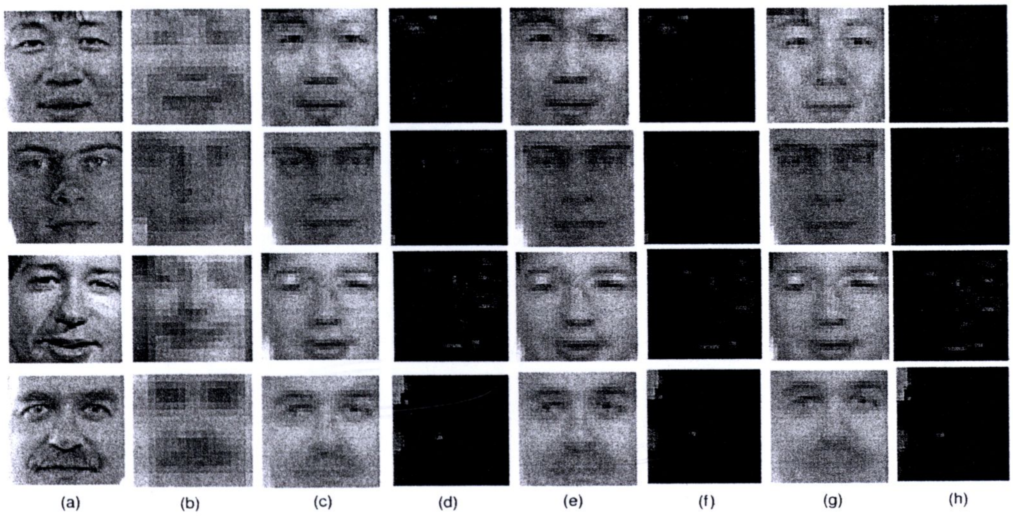

Figure 4.20: Color hallucinated face images with training set size 60 images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

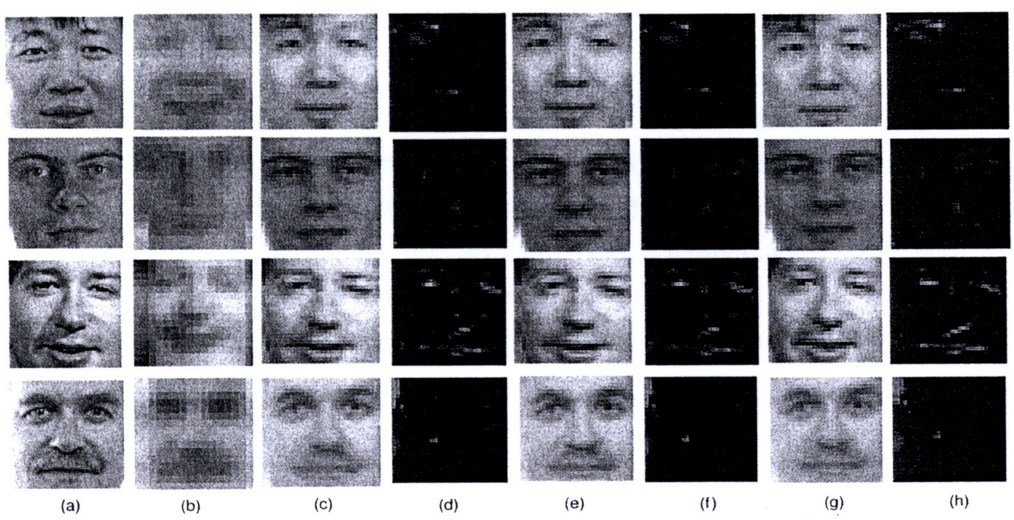

Figure 4.21: Color hallucinated face images with training set size 120 images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

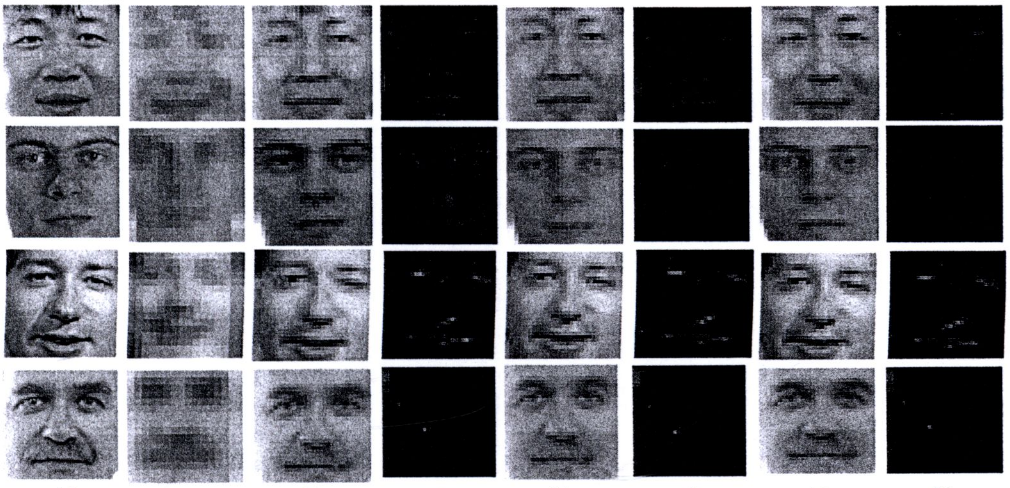

Figure 4.22: Color hallucinated face images with training set size 240 images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

4.4.3 Robustness to Noise

In this section, we add zero mean Gaussian noise with variance 10^{-6}, 2.5×10^{-5}, 2.5×10^{-4} and 10^{-3} to low-resolution face images. All the results are shown in Fig. 4.23-4.38: (a) the original HR (30×30) color images; (b) input the LR color images (15×15) with different noise variance ; (c), (e) and (g) face hallucination result with MPCA method; (d), (f) and (h) different image of face hallucination results. We can observe that the reconstructed color face images can remove most of the noise distortion and retain most of the facial characteristics.

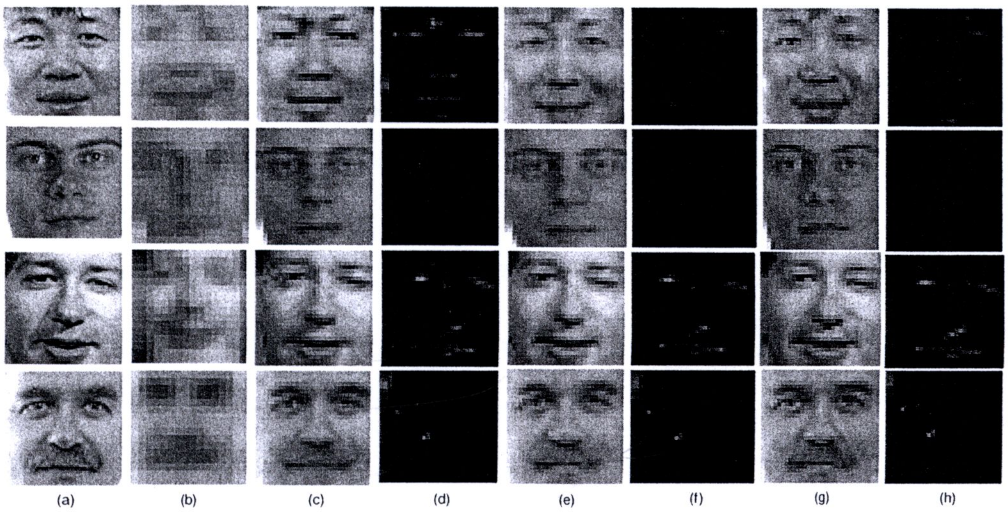

Figure 4.23: Color hallucinated face images with noise variance 10^{-6} in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

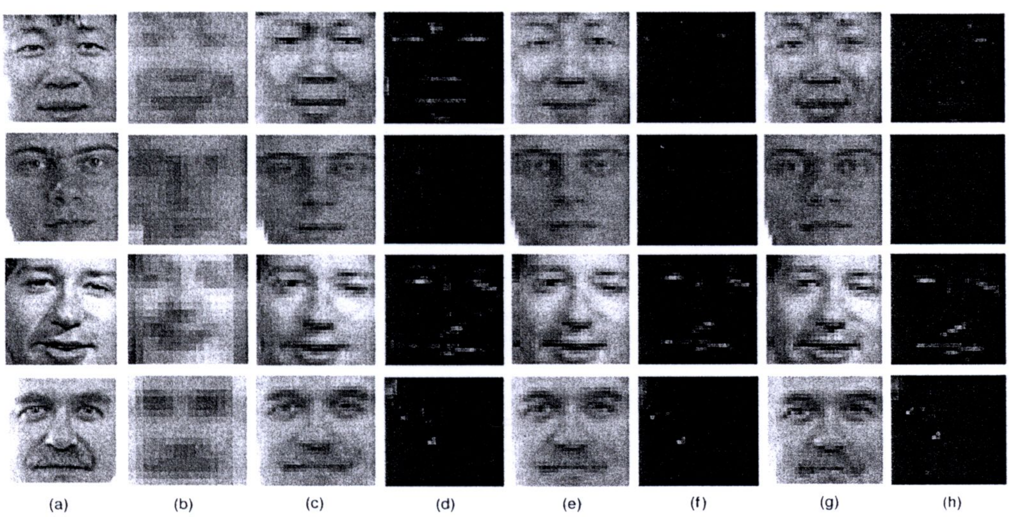

Figure 4.24: Color hallucinated face images with noise variance 2.5×10^{-5} in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-5}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

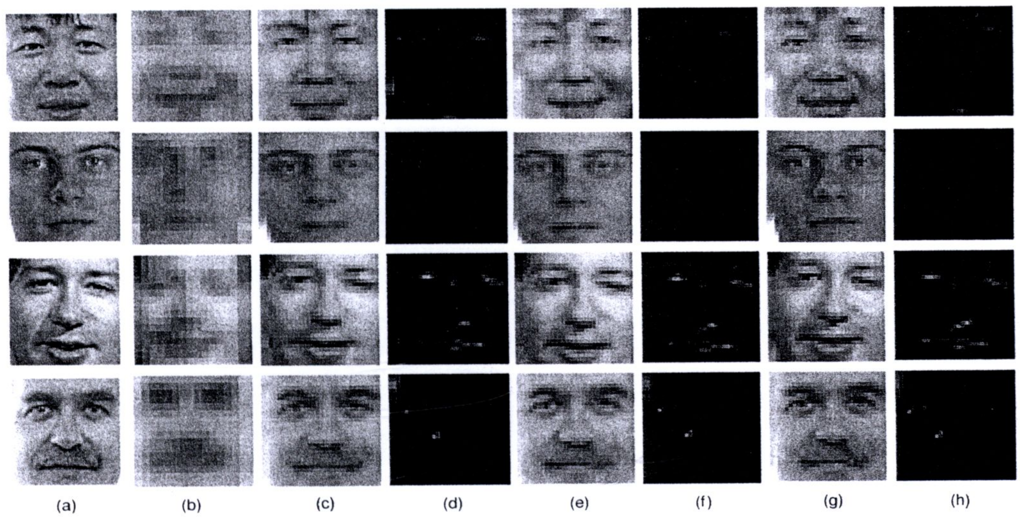

Figure 4.25: Color hallucinated face images with noise variance 2.5×10^{-4} in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-4}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

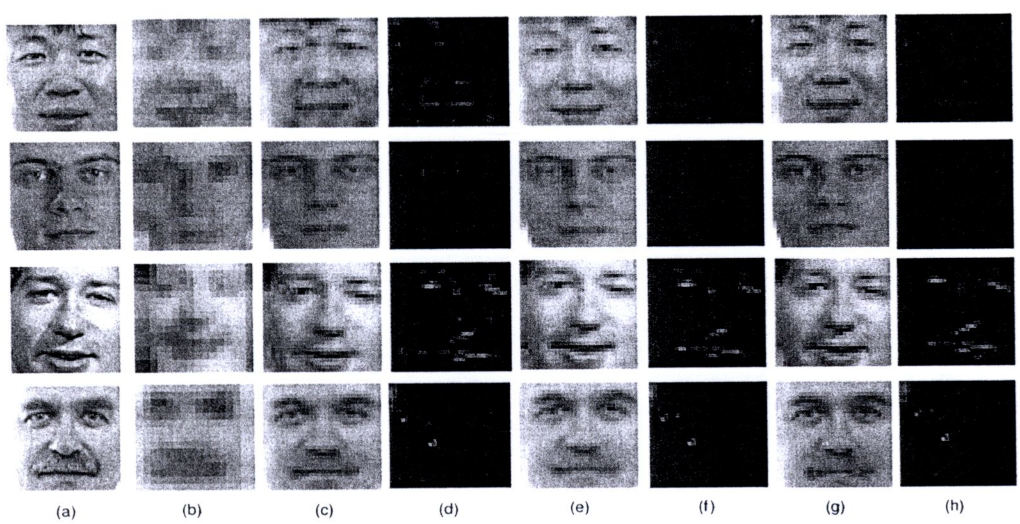

Figure 4.26: Color hallucinated face images with noise variance 10^{-3} in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-3}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

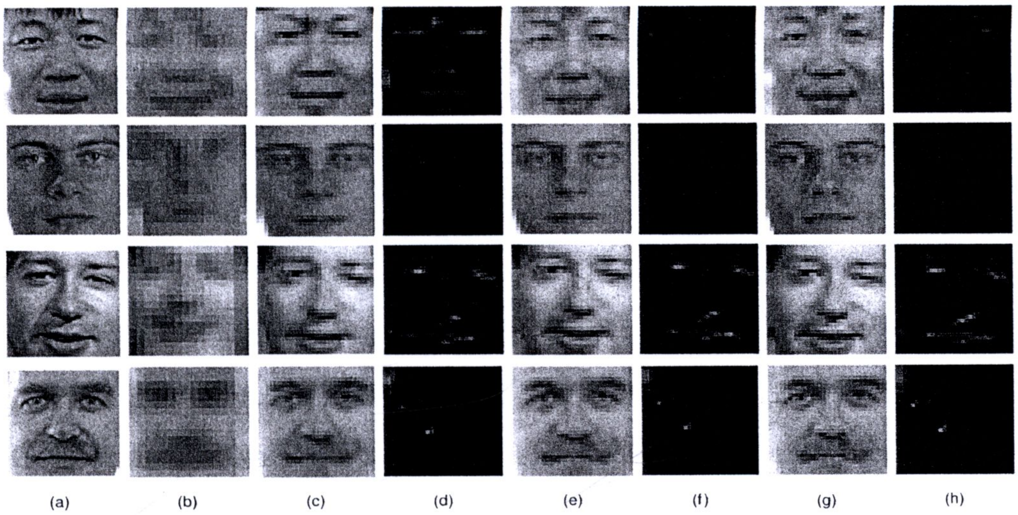

Figure 4.27: Color hallucinated face images with noise variance 10^{-6} in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

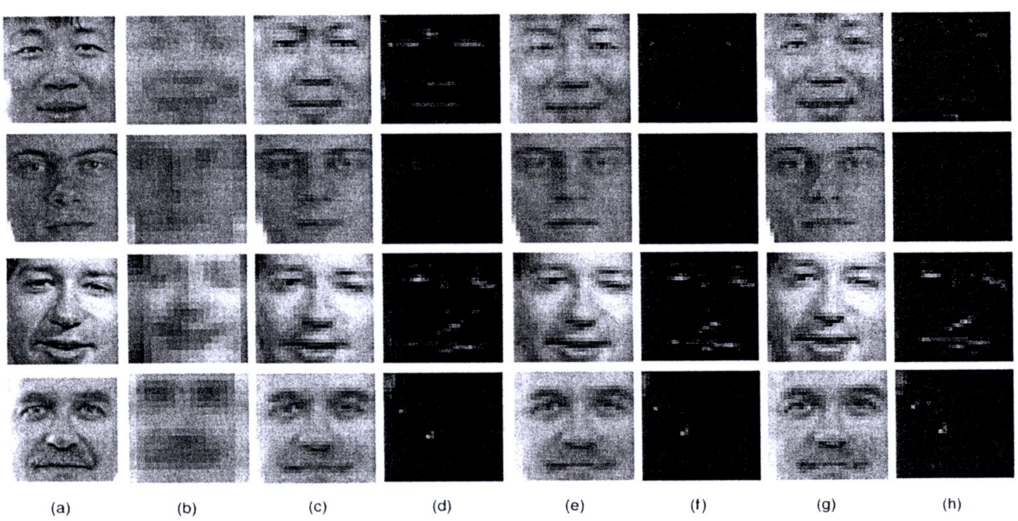

Figure 4.28: Color hallucinated face images with noise variance 2.5×10^{-5} in YCBCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

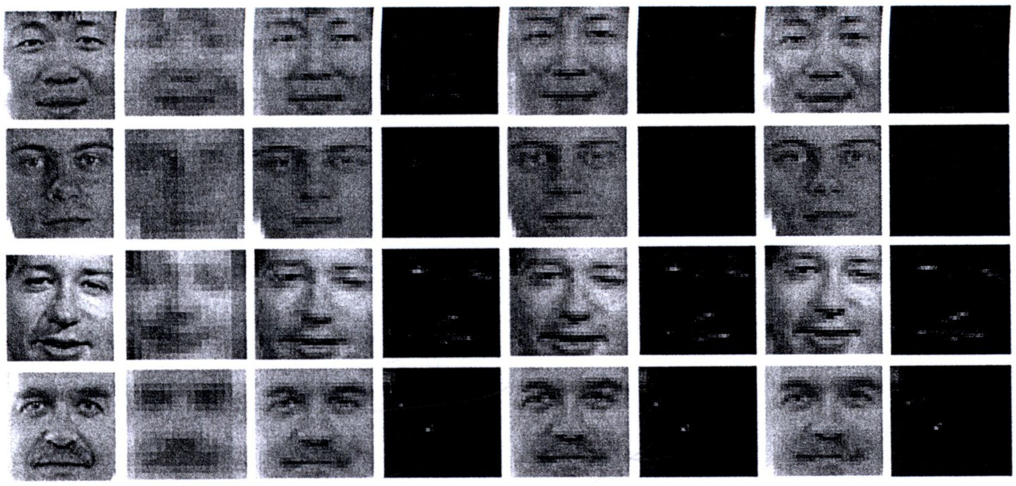

Figure 4.29: Color hallucinated face images with noise variance 2.5×10^{-4} in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-4}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

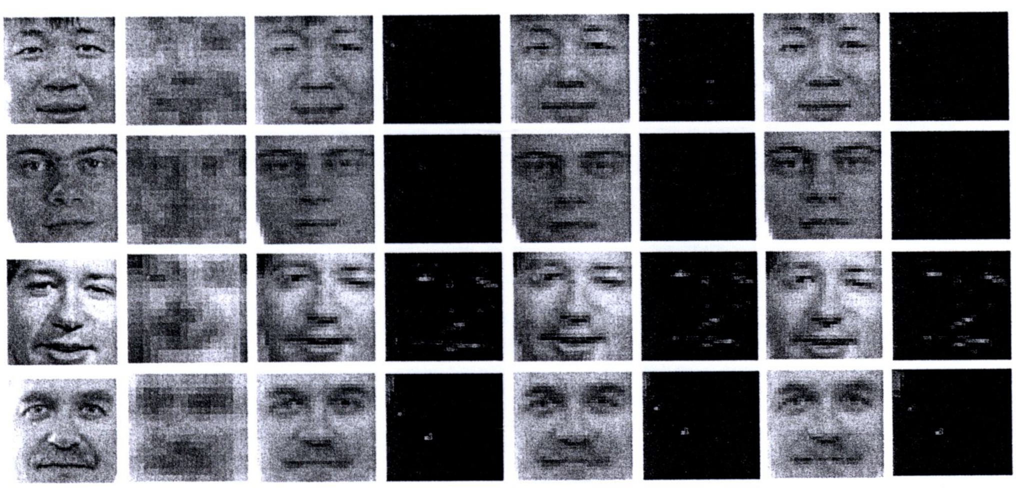

Figure 4.30: Color hallucinated face images with noise variance 10^{-3} in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-3}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

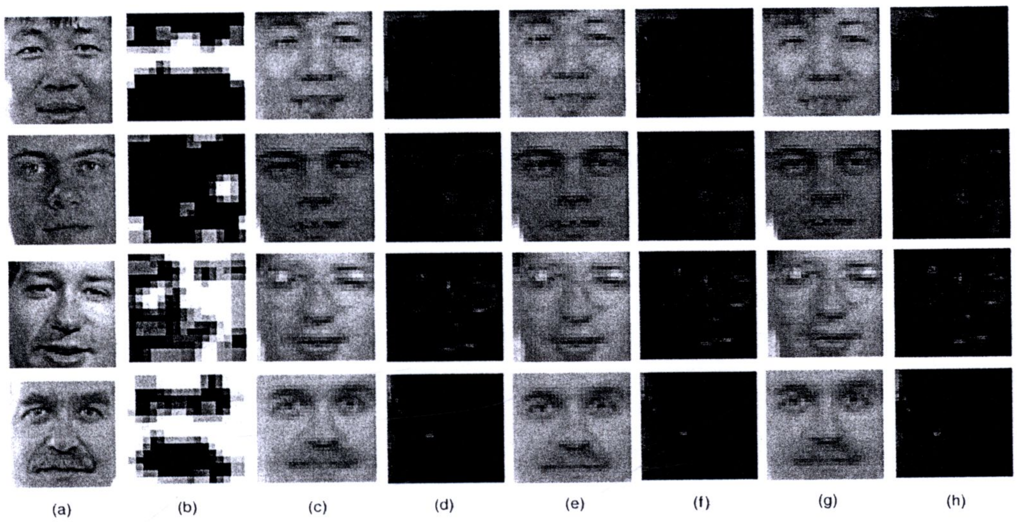

Figure 4.31: Color hallucinated face images with noise variance 10^{-6} in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

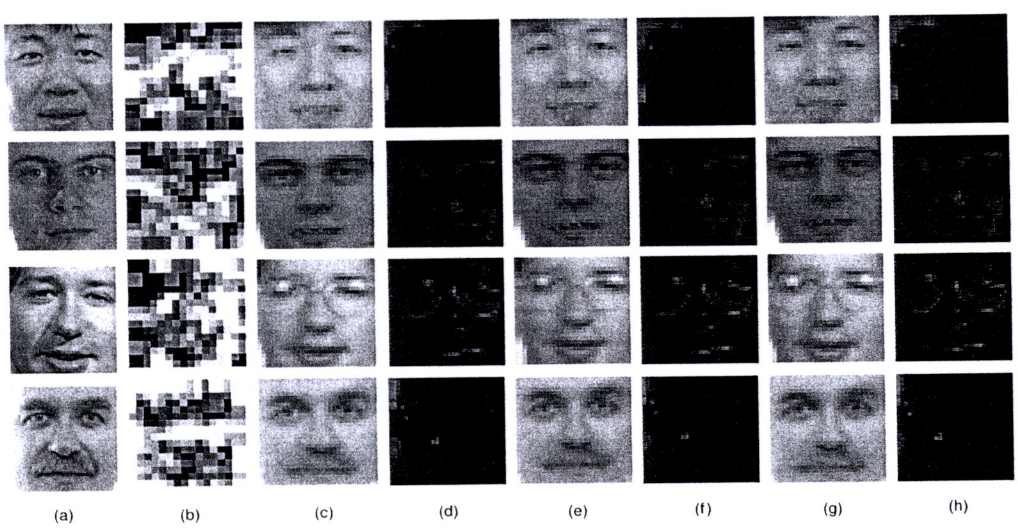

Figure 4.32: Color hallucinated face images with noise variance 2.5×10^{-5} in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-5}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

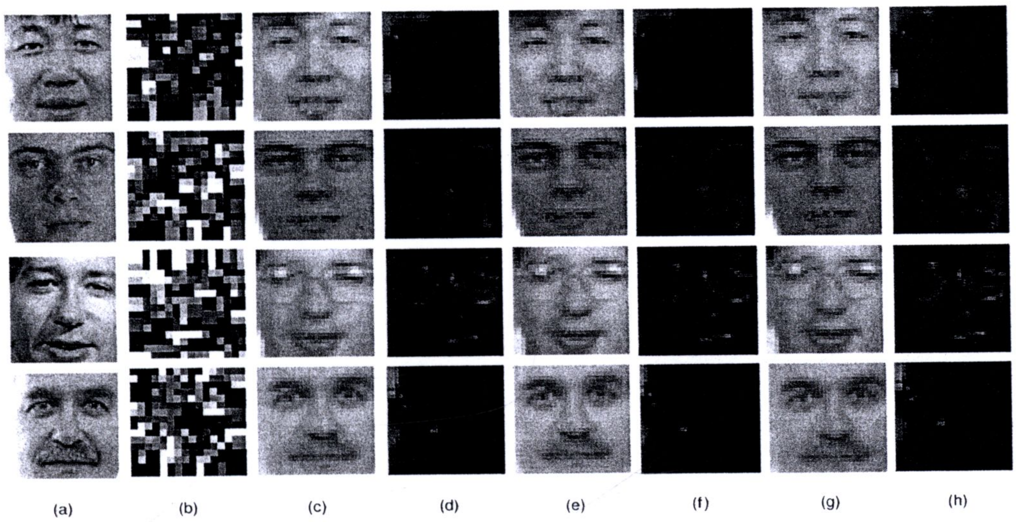

Figure 4.33: Color hallucinated face images with noise variance 2.5×10^{-4} in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-4}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

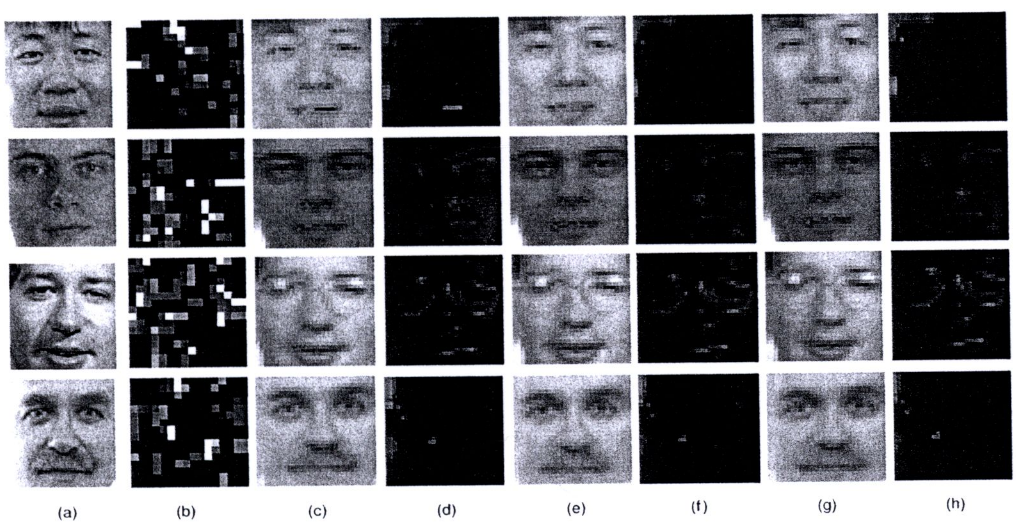

Figure 4.34: Color hallucinated face images with noise variance 10^{-3} in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-3}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

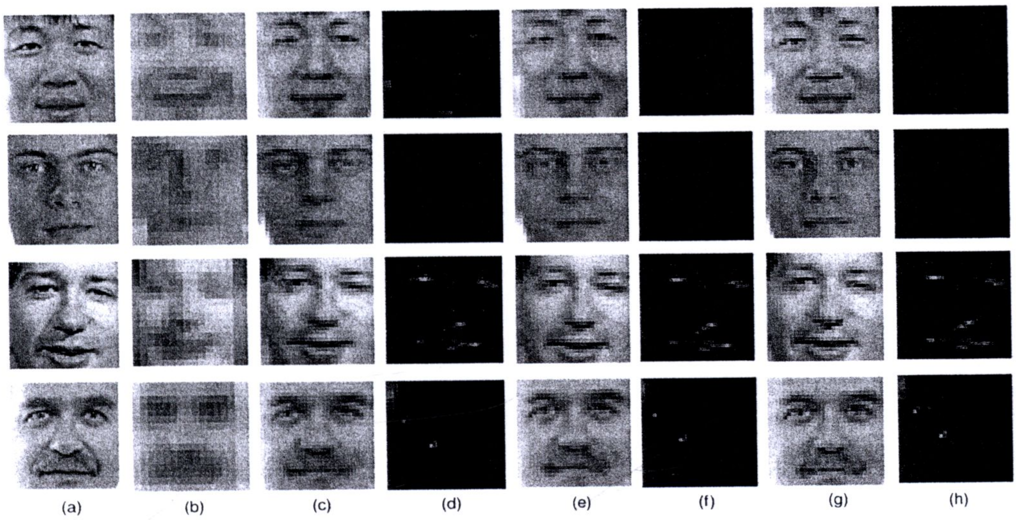

Figure 4.35: Color hallucinated face images with noise variance 10^{-6} in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

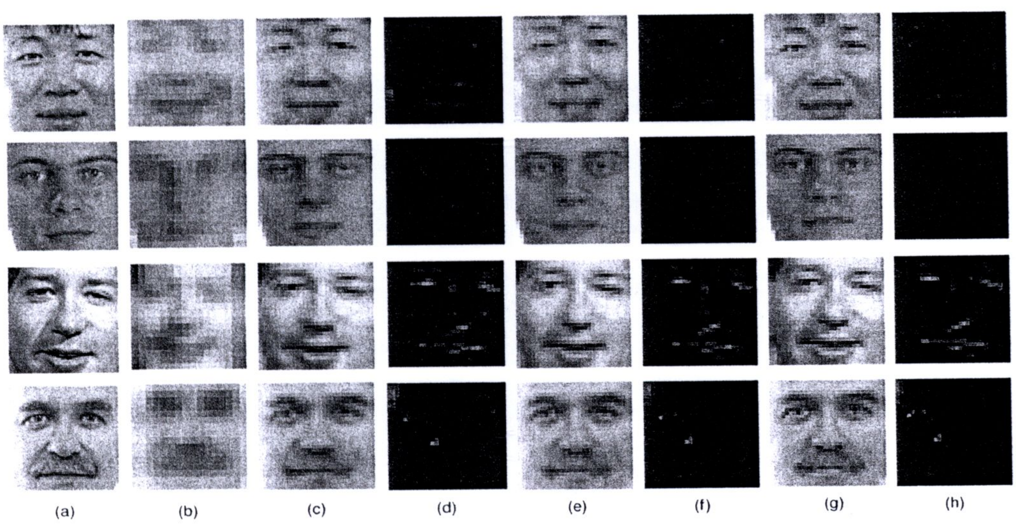

Figure 4.36: Color hallucinated face images with noise variance 2.5×10^{-5} in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-6}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

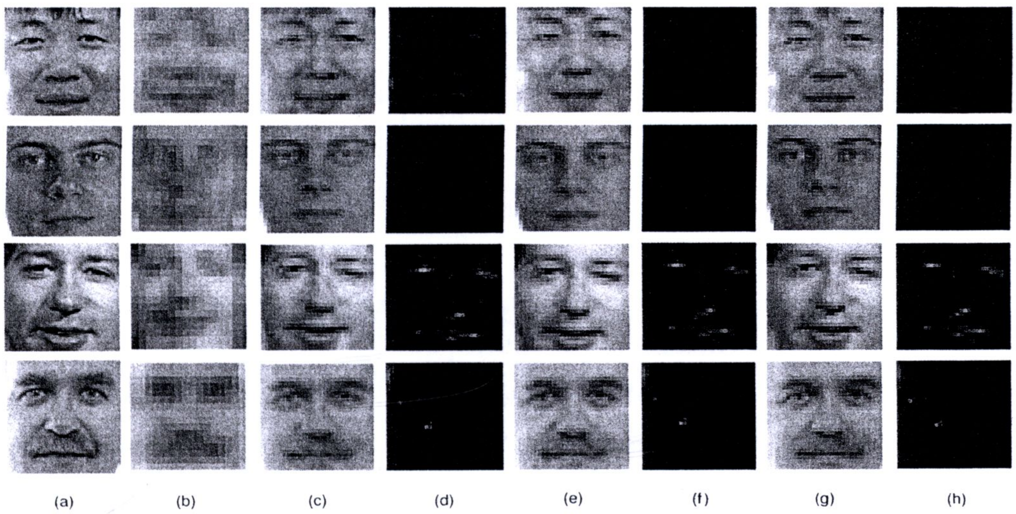

Figure 4.37: Color hallucinated face images with noise variance 2.5×10^{-4} in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-4}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

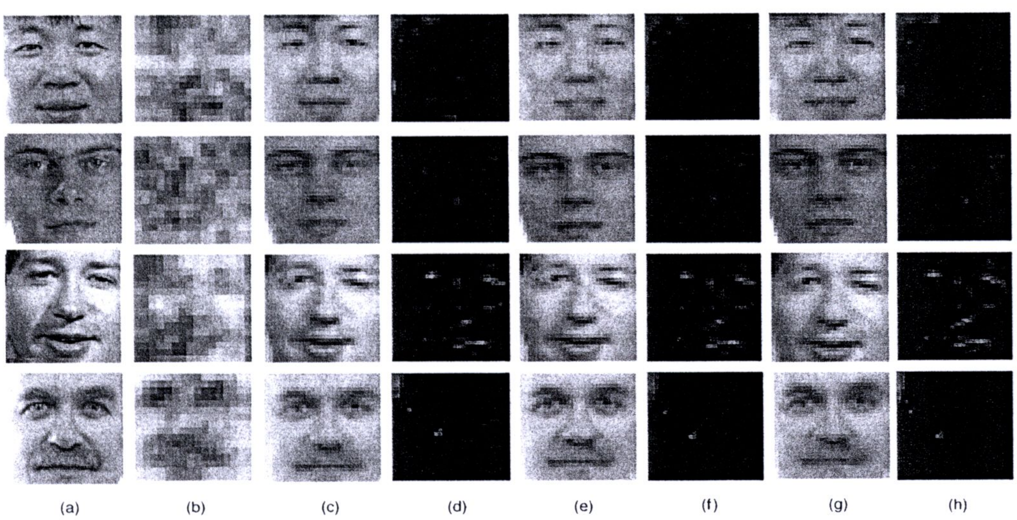

Figure 4.38: Color hallucinated face images with noise variance 10^{-3} in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise variance 10^{-3}, motion and blur in LR images; (c) face hallucination result with 90 percent MPCA; (d) different image of face hallucination result with 90 percent MPCA; (e) face hallucination result with 95 percent MPCA; (f) different image of face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) different image of face hallucination result with 100 percent MPCA;

Table 4.13 comparison of complexity (execution time) with training set size 60 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	14.403683 s.	14.676264 s.	15.586928 s.
2) $tensorPCA\ method$	14.756412 s.	14.935647 s.	15.894112 s.
3) $normalize$	1.0244	1.0176	1.0195

Table 4.14 comparison of complexity (execution time) with training set size 120 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	28.424068 s.	29.345926 s.	31.406217 s.
2) $tensorPCA\ method$	31.327327 s.	31.368005 s.	32.325575 s.
3) $normalize$	1.1021	1.0176	1.0292

4.4.4 Complexity

With regard to the computational complexity, we compare the execution time between our method and tensorPCA in RGB color model [33]. We test this experiment on a desktop-computer which is implemented on Microsoft Windows XP Professional 64 bits (version 2003), Intel(R) Core(TM)2 CPU 6600 with 2.8 GH and 3 GB of RAM and the result can be shown in Table. 4.13 - 4.16. For hallucination in MPCA method with 60, 120, 240 and 500 training sample images, the time in this simulation is about 14.40-15.58 seconds, 28.42-31.40 seconds, 58.70-65.27 seconds and 120.60-132.60 seconds respectively. However, with 60, 120, 240 and 500 training sample images, the method in [33] has a total time of 14.75-15.89 seconds, 31.32-32.32 seconds, 61.01-67.99 seconds and 132.99-133.69 respectively.

Moreover, in Table. 4.13 - 4.16, the tensorPCA method in independent channel color takes 1.01-1.1 times our algorithm time to implement similar results. The complexity of our algorithm, color face hallucination with MPCA, is less than the method in [33] because the MPCA can simultaneously reduce the dimension of data tensor (color face images) in PCA processes.

Table 4.15 comparison of complexity (execution time) with training set size 240 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	57.800732 s.	58.412280 s.	65.276072 s.
2) $tensorPCA\ method$	61.019110 s.	64.011103 s.	67.990804 s.
3) $normalize$	1.0556	1.0958	1.0415

Table 4.16 comparison of complexity (execution time) with training set size 500 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	120.603640 s.	122.589145 s.	132.603396 s.
2) $tensorPCA\ method$	132.994203 s.	133.472162 s.	133.696668 s.
3) $normalize$	1.1027	1.0887	1.0082

4.4.5 Partially Occluded Color Face Images

In this experiment, the regression model with MPCA also provides an ability to deal with the partially occluded face image and the blocking effect is used. Since the MPCA subspace analysis is still a holistic analysis method, we use a block for the partially occluded image patch. The experimental results are shown in Fig. 4.39-4.42 (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion, blur and left eye occluded; (c) face hallucination result with 100 percent traditional PCA; (d) face hallucination result with bilinear method and (e) face hallucination result with 95 percent MPCA. We can see that the traditional PCA and bilinear interpolation method are not suitable for hallucination facial images which are partially occluded. On the other hand, the linear regression model in MPCA can reconstruct realistic color face images.

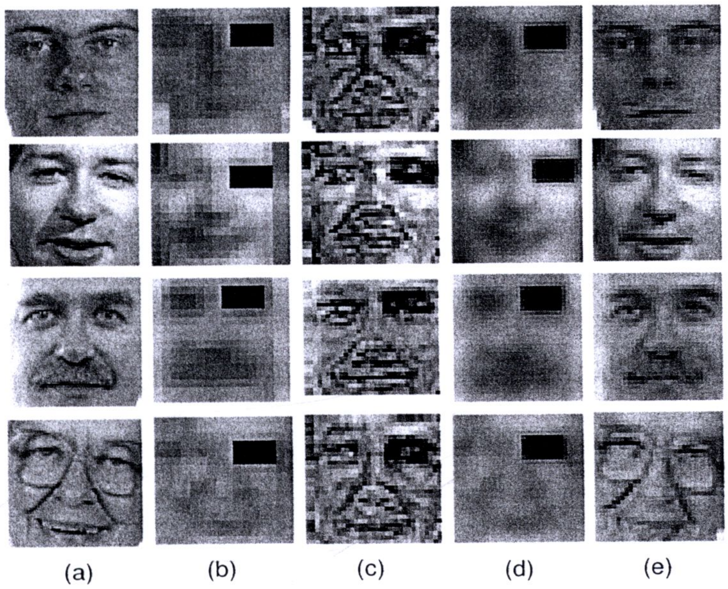

Figure 4.39: Partially occluded face hallucination results in RGB color model. (a) original HR images; (b) input LR images with noise, motion, blur and left eye occluded; (c) face hallucination result in RGB color model with 100 percent traditional PCA; (d) face hallucination result in RGB color model with bilinear method; (e) face hallucination result in RGB color model with 95 percent MPCA;

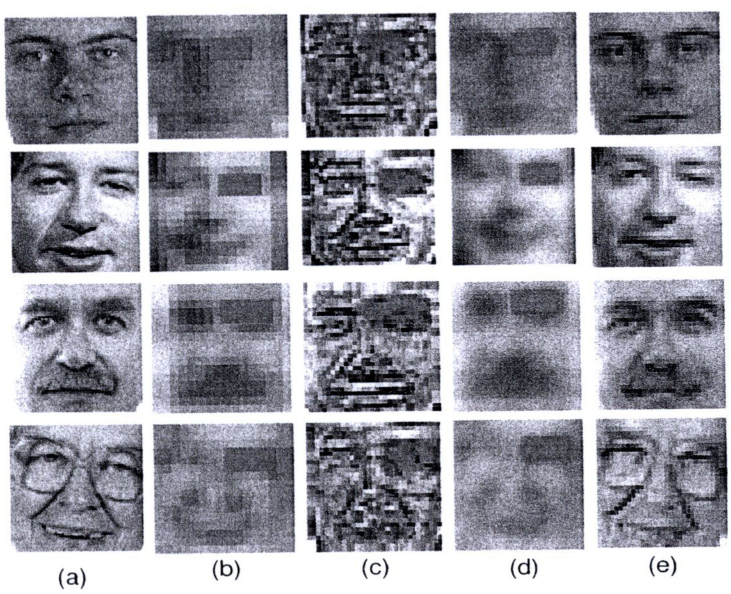

Figure 4.40: Partially occluded face hallucination results in YCbCr color model. (a) original HR images; (b) input LR images with noise, motion, blur and left eye occluded; (c) face hallucination result in YCbCr model system with 100 percent traditional PCA; (d) face hallucination result in YCbCr model system with bilinear method; (e) face hallucination result in YCbCr model system with 95 percent MPCA;

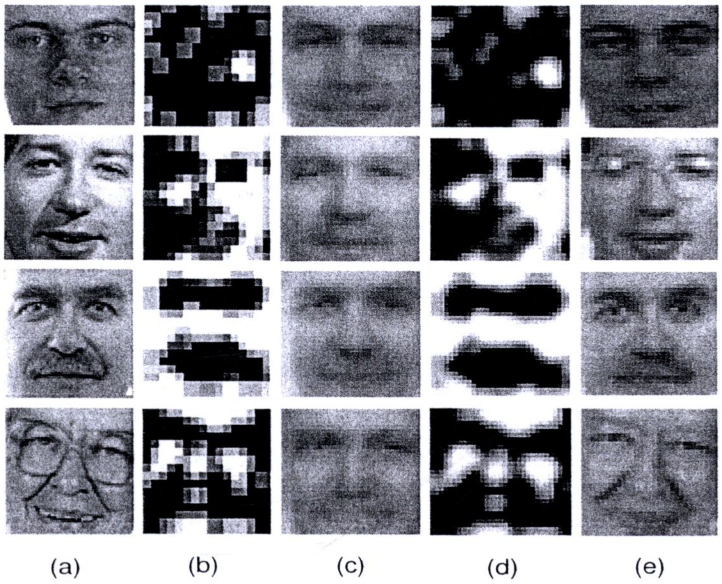

Figure 4.41: Partially occluded face hallucination results in HSV color model. (a) original HR images; (b) input LR images with noise, motion, blur and left eye occluded in HSV color model; (c) face hallucination result in HSV color model with 100 percent traditional PCA; (d) face hallucination result in HSV color model with bilinear method; (e) face hallucination result in HSV color model with 95 percent MPCA;

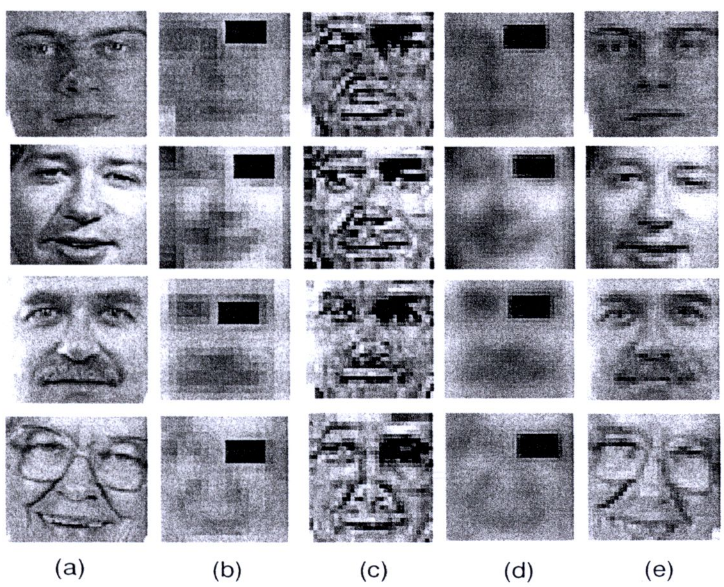

Figure 4.42: Partially occluded face hallucination results in CIELAB color model. (a) original HR images; (b) input LR images with noise, motion, blur and left eye occluded in CIELAB color model; (c) face hallucination result in CIELAB color model with 100 percent traditional PCA; (d) face hallucination result in CIELAB color model with bilinear method; (e) face hallucination result in CIELAB color model with 95 percent MPCA;

4.5 Experiments and Analysis on Color Face hallucination with Tensor Patch

In this experiment, we choose FERET database for a set of simulated experiments. There are 500 color faces for training set and other 50 facial images for testing. To establish a standard training dataset, we use a face image size of (30×30) and align the data manually by marking the location of three points: the centers of mouth and two eyes. These three points define an affine warp, which was used to warp the images into a canonical form. For all the 500 high-resolution facial images in the training dataset, we blurred and subsampled them to obtain their low-resolution (15×15) samples.

We decompose each of 500 pairs of low and high resolution training face images into (10×10) and (5×5) patches which overlapped horizontally and vertically with each other by 2 pixel and 4 pixel (the patch size and overlapping size were experimentally determined). We also quantify our performance by evaluating the peak signal-to-noise ratio (PSNR) between the ground truth face images and the hallucinated images.

Some experimental results are given in Fig. 4.43-4.58: (a) original HR images (30×30), (b) input LR images (15×15) with noise, motion and blur in LR images, (c) face hallucination result with bilinear interpolation method, (d) face hallucination result with Liu method, (e)-(g) face hallucination result with 90 - 100 percent MPCA and (h) face hallucination result with Tensor patch method. The results in column (h) shows that tensor patches technique is good at hallucinating and reproducing details of local face regions, but poor at detail around an eye. We also give in Table. 4.17-4.20 the PSNR values between the hallucinated face images with linear regression model in MPCA and those face hallucination results with tensor patches in Fig. 4.43-4.58. Table 4.43-4.58 show that our proposed approach outperforms all the other face super-resolution techniques in terms of PSNR.

We compare our method with difference patch size, some example results are presented in Fig. 4.43-4.58. Compared with the results in Fig. 4.43-4.50 (h) using tensor patches technique with size (5×5), the hallucinated results in Fig. 4.51-4.58 (h) tensor patches technique with size (10×10) then the bigger patch size can produce better color facial results than small patch size. In addition, with the same value of percent MPCA, the tensor patch method with size (10×10) can give higher PSNR values than size (5×5) about 0.19 - 1.24 dB.

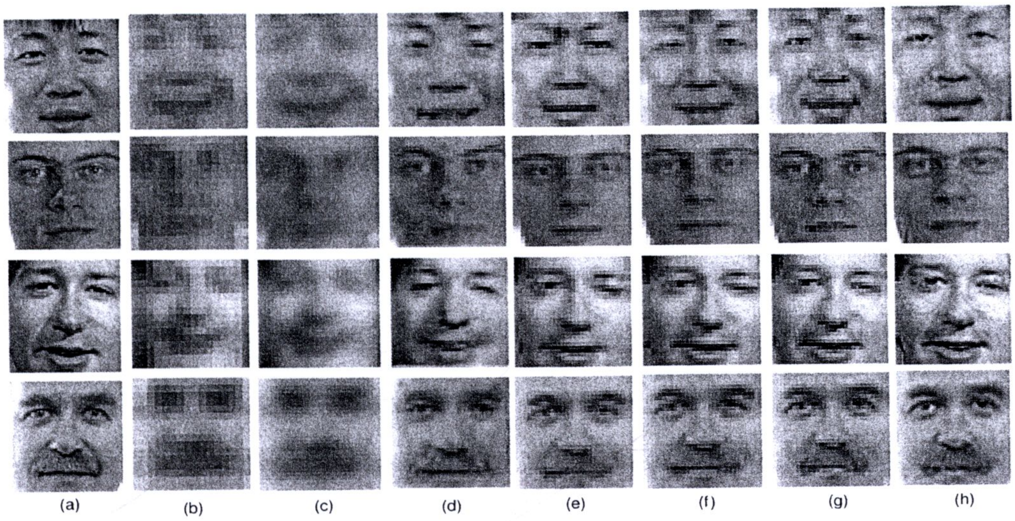

Figure 4.43: Color hallucinated face images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 95 percent MPCA;

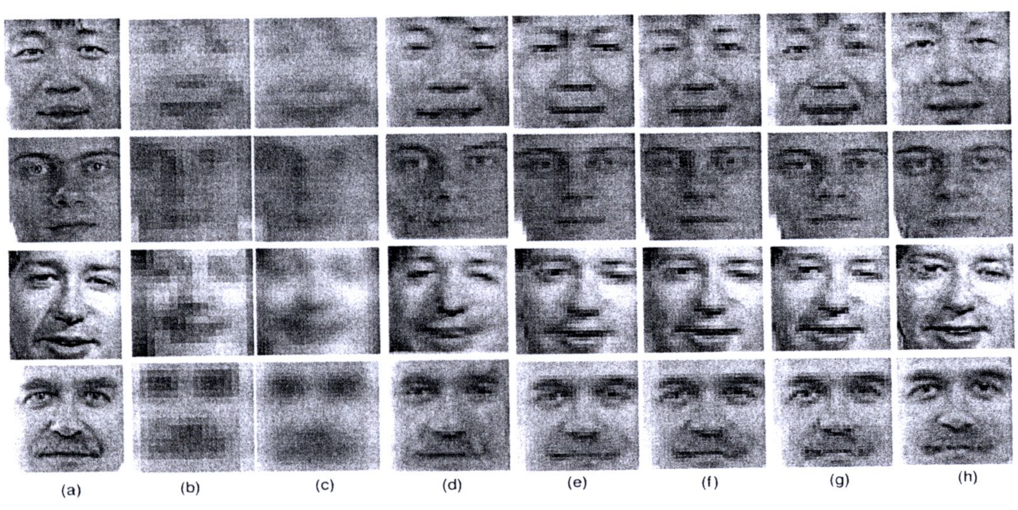

Figure 4.44: Color hallucinated face images in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 95 percent MPCA;

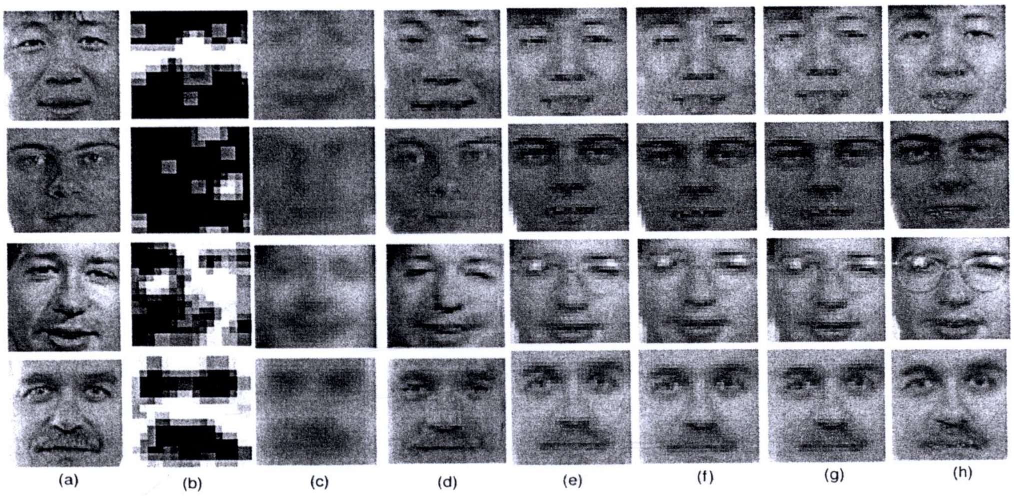

Figure 4.45: Color hallucinated face images in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 95 percent MPCA;

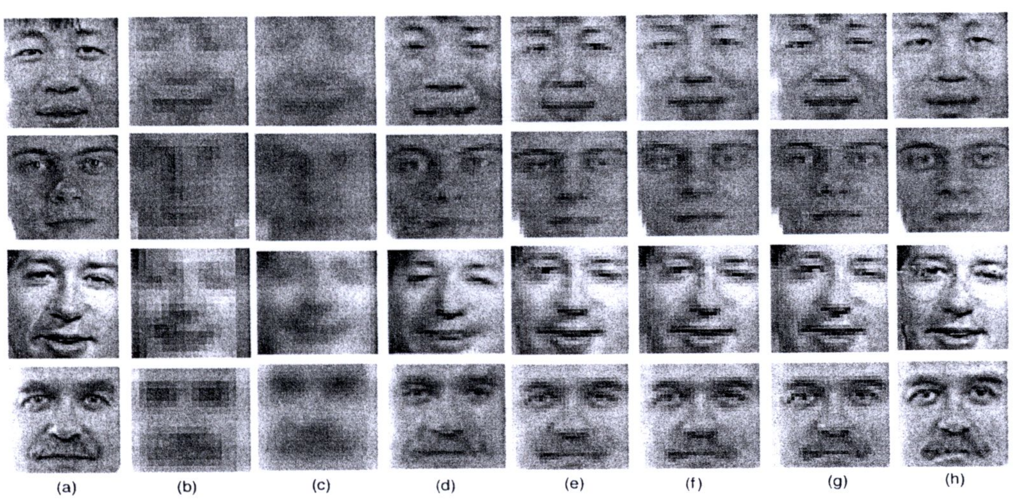

Figure 4.46: Color hallucinated face images in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 95 percent MPCA;

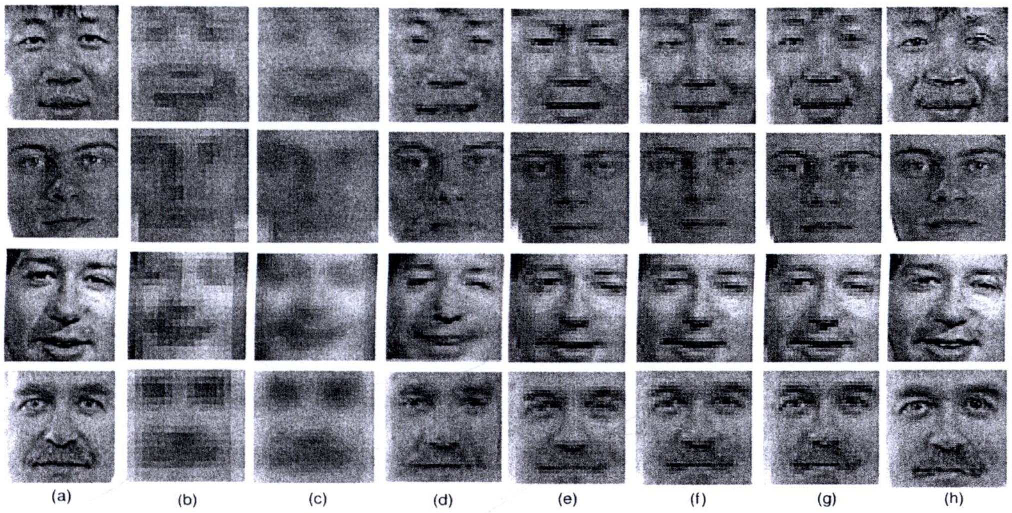

Figure 4.47: Color hallucinated face images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 100 percent MPCA;

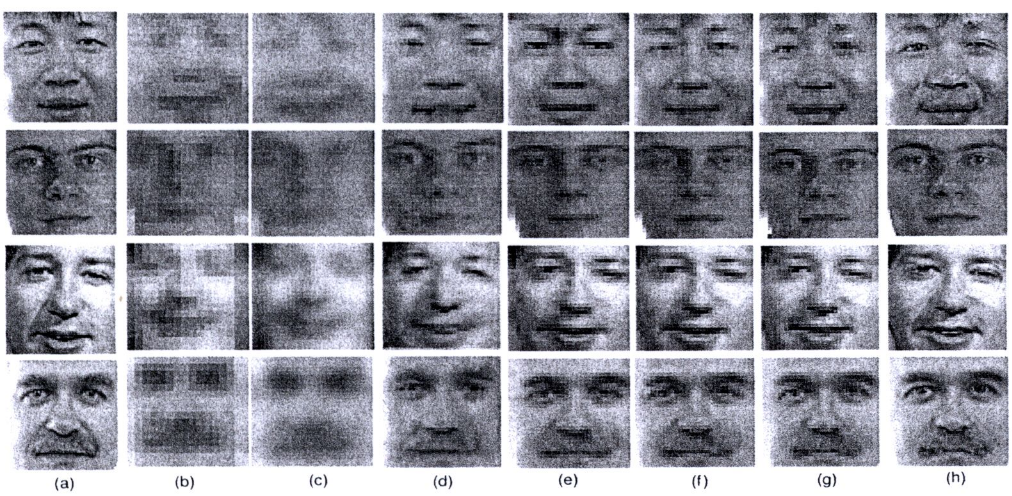

Figure 4.48: Color hallucinated face images in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 100 percent MPCA;

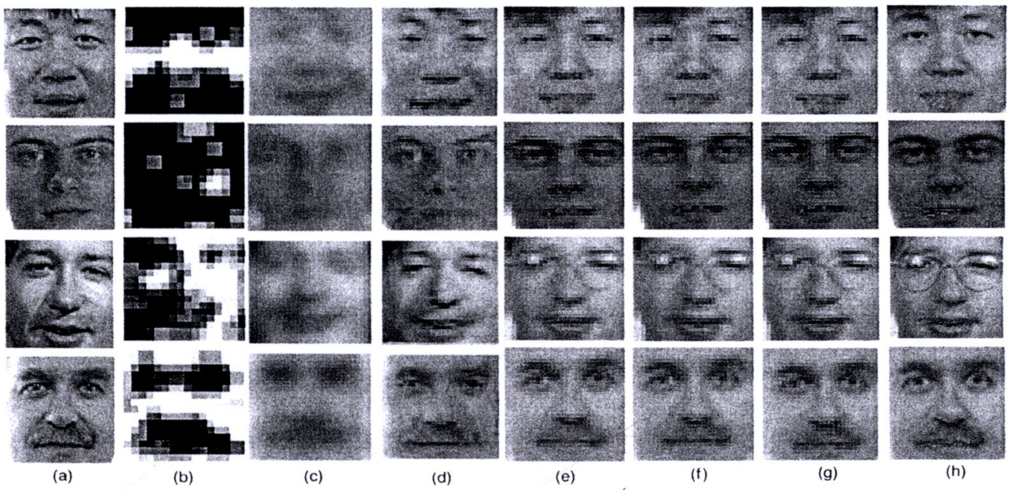

Figure 4.49: Color hallucinated face images in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 100 percent MPCA;

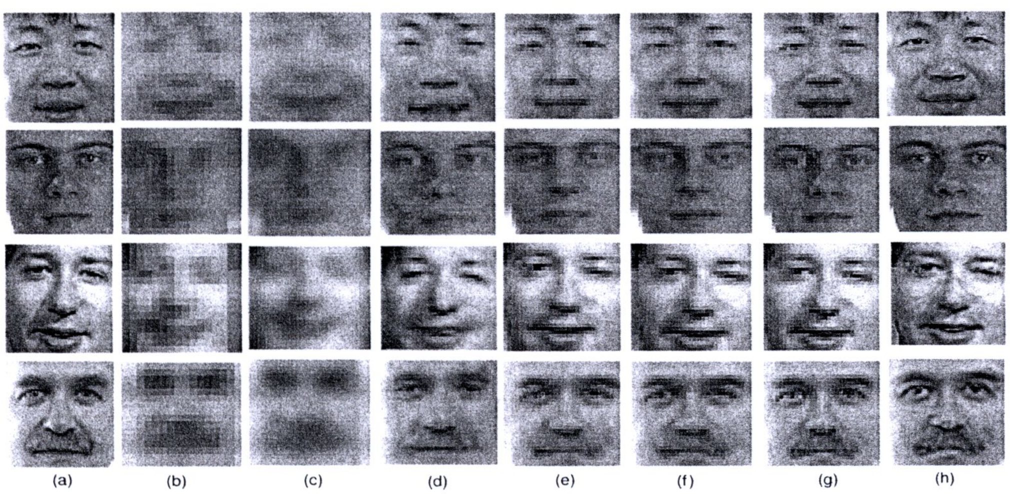

Figure 4.50: Color hallucinated face images in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (5×5) patches method and 95 percent MPCA;

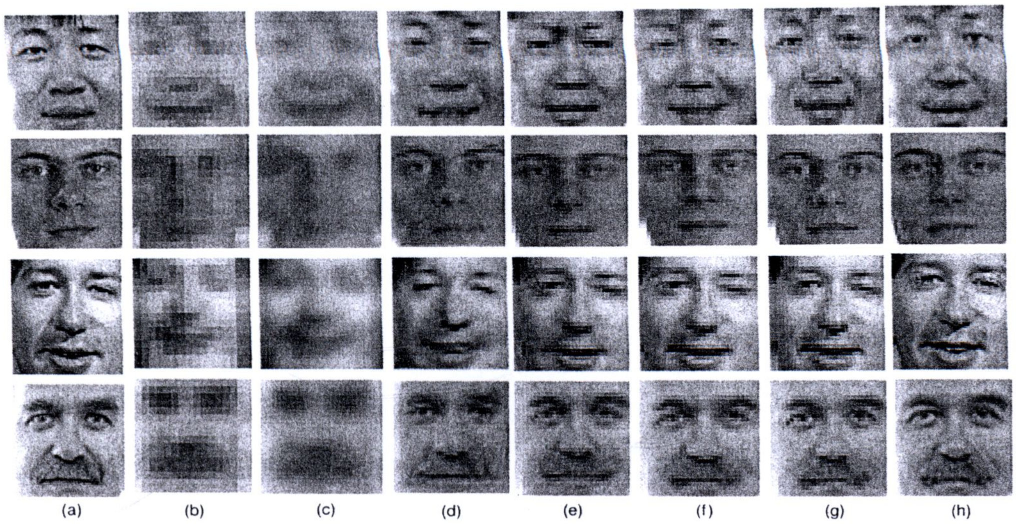

Figure 4.51: Color hallucinated face images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 95 percent MPCA;

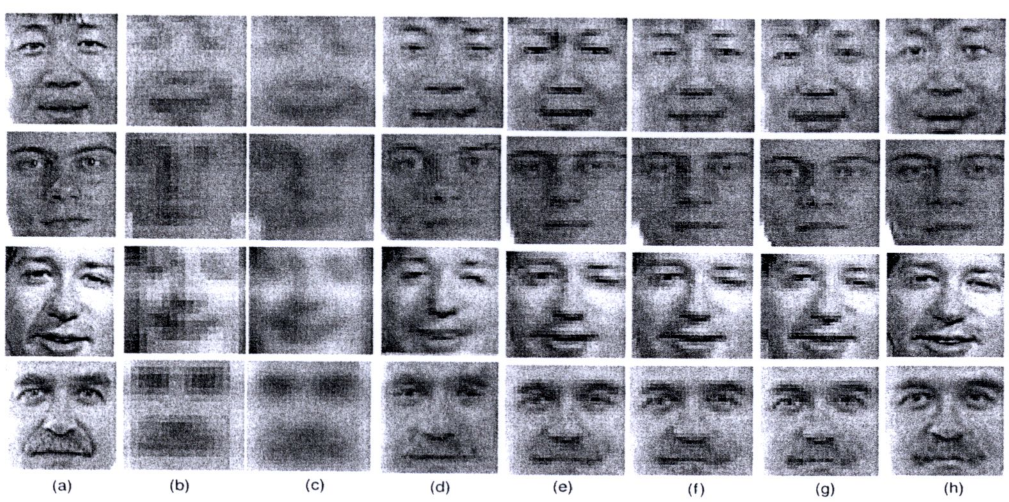

Figure 4.52: Color hallucinated face images in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 95 percent MPCA;

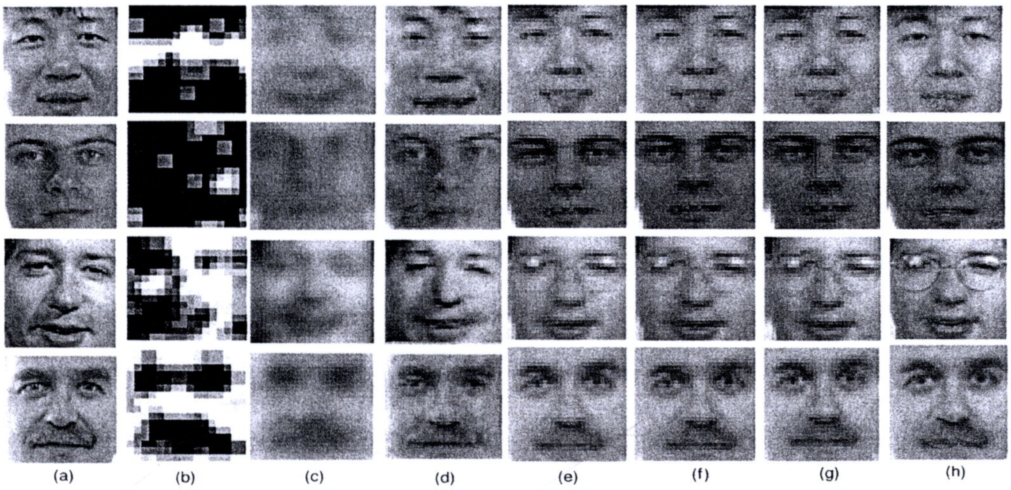

Figure 4.53: Color hallucinated face images in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 95 percent MPCA;

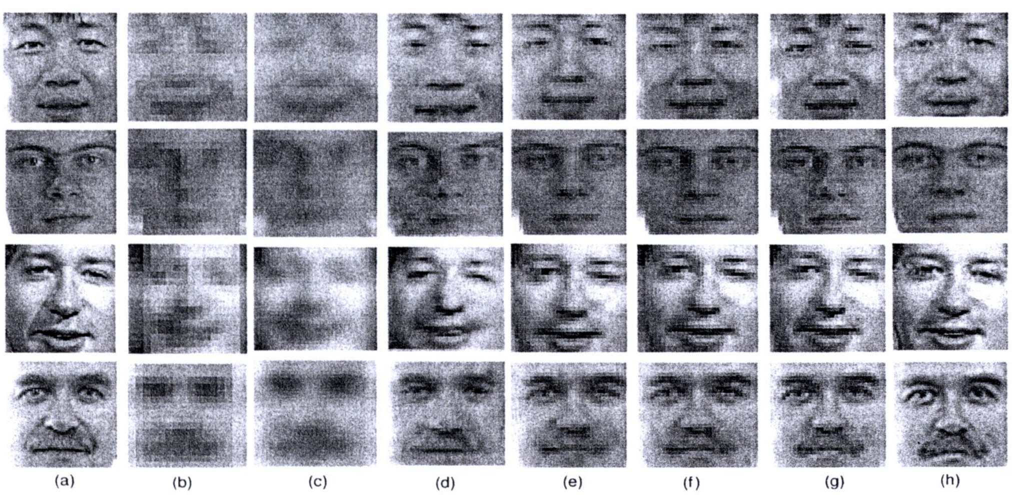

Figure 4.54: Color hallucinated face images in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 95 percent MPCA;

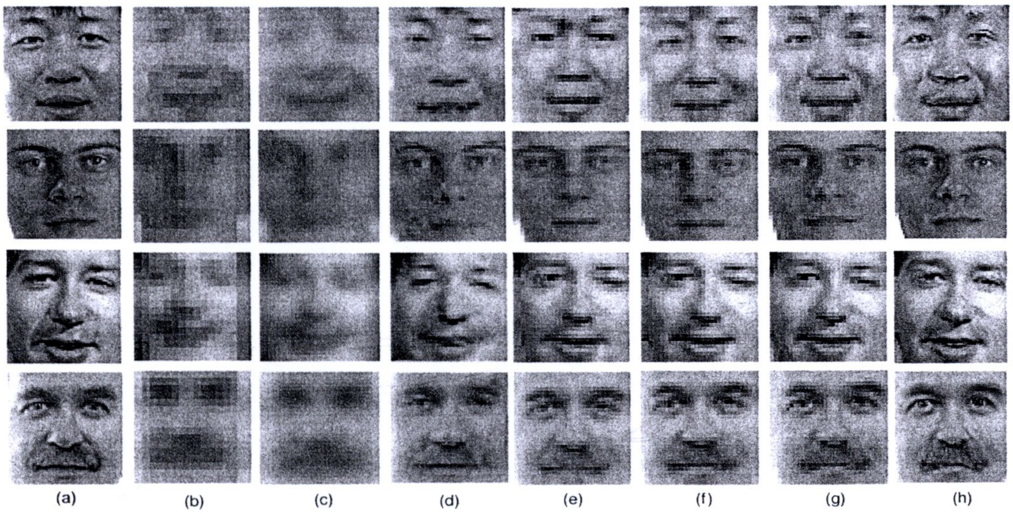

Figure 4.55: Color hallucinated face images in RGB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 100 percent MPCA;

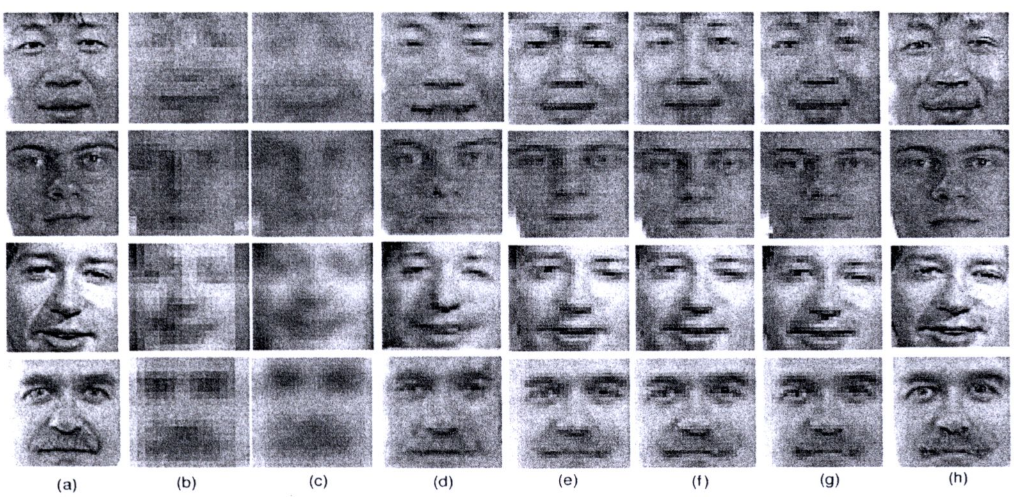

Figure 4.56: Color hallucinated face images in YCbCr color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 100 percent MPCA;

Figure 4.57: Color hallucinated face images in HSV color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 100 percent MPCA;

Table 4.17: PSNR results of the facial images with tensor patches method in Fig. 4.43 - 4.58 for RGB color model.

Case	first row	second row	third row	fourth row
1) 90 *percent MPCA*	26.88 dB	35.91 dB	27.89 dB	30.14 dB
2) 95 *percent MPCA*	31.15 dB	36.91 dB	28.53 dB	30.78 dB
3) 100 *percent MPCA*	31.35 dB	40.23 dB	28.74 dB	30.98 dB
4) *patch* (5×5) *with* 95 *percent MPCA*	34.19 dB	41.15 dB	32.32 dB	35.69 dB
5) *patch* (5×5) *with* 100 *percent MPCA*	34.68 dB	42.23 dB	32.45 dB	35.78 dB
6) *patch* (10×10) *with* 95 *percent MPCA*	35.28 dB	41.86 dB	32.67 dB	35.87 dB
7) *patch* (10×10) *with* 100 *percent MPCA*	35.92 dB	42.71 dB	32.85 dB	36.26 dB

Figure 4.58: Color hallucinated face images in CIELAB color model. (a) original HR images (30×30); (b) input LR images (15×15) with noise, motion and blur in LR images; (c) face hallucination result with bilinear interpolation method; (d) face hallucination result with Liu method; (e) face hallucination result with 90 percent MPCA; (f) face hallucination result with 95 percent MPCA; (g) face hallucination result with 100 percent MPCA; (h) face hallucination result with Tensor (10×10) patches method and 100 percent MPCA;

Table 4.18: PSNR results of the facial images with tensor patches method in Fig. 4.43 - 4.58 for YCbCr color model.

Case	first row	second row	third row	fourth row
1) $90\ percent\ MPCA$	27.03 dB	36.38 dB	27.93 dB	30.13 dB
2) $95\ percent\ MPCA$	31.24 dB	37.04 dB	28.57 dB	30.69 dB
3) $100\ percent\ MPCA$	31.47 dB	40.29 dB	28.84 dB	30.88 dB
4) $patch\ (5 \times 5)\ with\ 95\ percent\ MPCA$	34.59 dB	41.27 dB	32.39 dB	35.73 dB
5) $patch\ (5 \times 5)\ with\ 100\ percent\ MPCA$	35.10 dB	42.35 dB	32.55 dB	35.84 dB
6) $patch\ (10 \times 10)\ with\ 95\ percent\ MPCA$	34.87 dB	41.88 dB	32.66 dB	35.91 dB
7) $patch\ (10 \times 10)\ with\ 100\ percent\ MPCA$	35.32 dB	42.78 dB	32.93 dB	36.34 dB

Table 4.19: PSNR results of the facial images with tensor patches method in Fig. 4.43 - 4.58 for HSV color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ MPCA$	26.85 dB	31.02 dB	27.71 dB	29.41 dB
2) 95 $percent\ MPCA$	27.28 dB	31.18 dB	27.87 dB	29.59 dB
3) 100 $percent\ MPCA$	27.75 dB	31.22 dB	27.96 dB	29.63 dB
4) $patch\ (5 \times 5)\ with$ 95 $percent\ MPCA$	33.20 dB	31.25 dB	31.22 dB	34.57 dB
5) $patch\ (5 \times 5)\ with$ 100 $percent\ MPCA$	33.36 dB	31.31 dB	31.24 dB	34.61 dB
6) $patch\ (10 \times 10)\ with$ 95 $percent\ MPCA$	33.32 dB	31.41 dB	31.28 dB	34.70 dB
7) $patch\ (10 \times 10)\ with$ 100 $percent\ MPCA$	33.41 dB	31.49 dB	31.35 dB	34.78 dB

Table 4.20: PSNR results of the facial images with tensor patches method in Fig. 4.43 - 4.58 for CIELAB color model.

Case	first row	second row	third row	fourth row
1) 90 $percent\ MPCA$	29.59 dB	36.48 dB	28.01 dB	30.58 dB
2) 95 $percent\ MPCA$	31.66 dB	37.11 dB	28.35 dB	31.52 dB
3) 100 $percent\ MPCA$	32.08 dB	40.35 dB	28.69 dB	31.69 dB
4) $patch\ (5 \times 5)\ with$ 95 $percent\ MPCA$	35.21 dB	41.31 dB	32.39 dB	35.75 dB
5) $patch\ (5 \times 5)\ with$ 100 $percent\ MPCA$	36.15 dB	42.40 dB	32.48 dB	35.89 dB
6) $patch\ (10 \times 10)\ with$ 95 $percent\ MPCA$	35.47 dB	41.52 dB	32.71 dB	35.97 dB
7) $patch\ (10 \times 10)\ with$ 100 $percent\ MPCA$	36.39 dB	42.82 dB	32.96 dB	36.44 dB

Table 4.21: comparison of complexity (execution time) between tensor patch method and MPCA method with training set size 60 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	14.403683 s.	14.676264 s.	15.586928 s.
2) $tensor\ patch\ size\ (10 \times 10)$	32.445231 s.	39.667863 s.	59.889969 s.
3) $tensor\ patch\ size\ (5 \times 5)$	253.547854 s.	287.634373 s.	304.315276 s.

Table 4.22: comparison of complexity (execution time) between tensor patch method and MPCA method with training set size 120 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	28.424068 s.	29.345926 s.	31.406217 s.
2) $tensor\ patch\ size\ (10 \times 10)$	68.749302 s.	77.146453 s.	111.857586 s.
3) $tensor\ patch\ size\ (5 \times 5)$	512.846542 s.	574.463359 s.	664.599841 s.

4.5.1 Complexity

In this section, we compare the execution time between the tensor patch method and MPCA method. The execution time results are come from a desktop-computer which is implemented on Microsoft Windows XP Professional 64 bits (version 2003), Intel(R) Core(TM)2 CPU 6600 with 2.8 GH and 3 GB of RAM and the result can be shown in Table. 4.21 - 4.24.

For hallucination in MPCA method with 60, 120, 240 and 500 training sample images, the time in this simulation is about 14.40-15.58 seconds, 28.42-31.40 seconds, 58.70-65.27 seconds and 120.60-132.60 seconds respectively but the execution time of tensor patch method with size (10×10) is about 32.44-59.88 seconds, 68.74-111.85 seconds, 146.70-223.09 seconds and 290.16-461.16 seconds respectively. In addition, in Table. 4.21 - 4.24, we can see that the execution time of tensor patch method with size (5×5) will increase rapidly from 253.54 seconds to 2798.165270 seconds when training sample increase from 60 to 500 images.

Table 4.23: comparison of complexity (execution time) between tensor patch method and MPCA method with training set size 240 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	57.800732 s.	58.412280 s.	65.276072 s.
2) $tensor\ patch\ size\ (10 \times 10)$	146.709354 s.	159.184390 s.	223.091005 s.
3) $tensor\ patch\ size\ (5 \times 5)$	1014.458788 s.	1143.303170 s.	1244.944058 s.

Table 4.24: comparison of complexity (execution time) between tensor patch method and MPCA method with training set size 500 images

Case	90 percent	95 percent	100 percent
1) $MPCA\ method$	120.603640 s.	122.589145 s.	132.603396 s.
2) $tensor\ patch\ size\ (10 \times 10)$	290.167969 s.	344.809926 s.	461.160870 s.
3) $tensor\ patch\ size\ (5 \times 5)$	2513.275331 s.	2659.911861 s.	2798.165270 s.