# CHAPERT IV

# RESULTS AND DISCUSSIONS

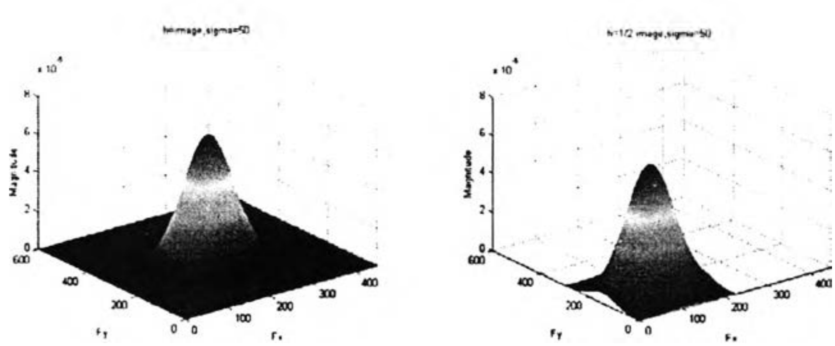
The model of image color appearance iCAM was successfully implemented to apply to render images. The characteristics of low-pass filters utilized in the model were changed by varying two important parameters of the filters: size and sigma ($\sigma$). The results for the effects of these two parameters on the characteristics of low-pass filters are given in Section 4.1. The other method used to enhance original images in this study was the function Imadjust provided in Image Processing Toolbox in MATLAB. Variables required in Imadjust were also varied in this study. The results are shown in Section 4.2. Section 4.3 shows the results for suitable variables applied to iCAM and Imadjust. Finally, the resulting images from iCAM and Imadjust, together with the reference image and the original image were visually compared and the results are given in Section 4.4.

## 4.1 Characteristics of low-pass filters.

In iCAM, the Gaussian filter is employed to get low-pass images, in order to obtain information on chromatic and luminance adaptation from the low-pass adapting images. The Gaussian blurring has two parameters that influence the characteristics of the filter, i.e. the size of filter and $\sigma$ (sigma). These two parameters were varied and the results are given in the following sections.

4.1.1 Effects of filter size.

In iCAM, the cone RGB adaptation signals are derived from the low-pass adaptation image, i.e. the image obtained through the process of image filtering using Gaussian filter. These cone signals are later used to compute corresponding colors. In the present study, two sizes of this filter were tested to investigate its impact on image enhancement with iCAM. The two sizes of filter were the size of image it was applied and a half of the image size. Figure 4-1 shows the characteristics of Gaussian filter in the surface plot, when different sizes were applied with a constant sigma. It can be seen that the distributions of filter values are not much different around the center area. When applying a filter to an image, the image data are convolved by multiplying each pixel by all data in the filter. When the large filter was used, more numbers of data were applied to each image's pixel than when the small filter was used. The large filter had more effective neighboring pixels of its center than the small filter. However, the main contributions to images were not much different.



(a) (b)

*Figure 4-1: Characteristics of Gaussian filter with a constant sigma but two different sizes (a) filter size equal to image size (b) filter size equal to 1/2 image size.*

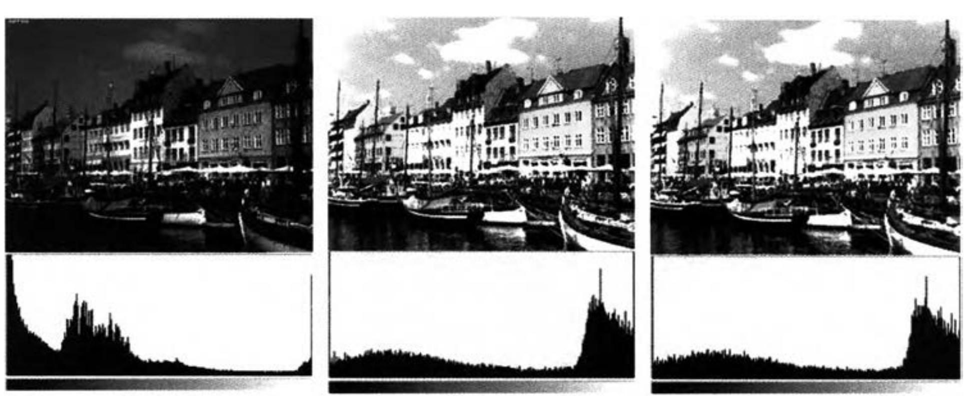
Figure 4-2 shows the resulting images obtained when applying the two filters presented in Figure 4-1 through the process of iCAM. Note that in iCAM the Gaussian filter is applied in two parts: first, to obtain the cone RGB adaptation signals ($R_wG_wB_w$) in chromatic adaptation part, and second, to obtain the adapting luminance in the luminance adaptation part. Thus the filters applied are called the first, and the second filter, accordingly, throughout this thesis.

(a) (b) (c)

*Figure 4-2: The resulting images (a) the original image (b) the image using larger size of the first filter (c) the image using the first filter 1/2 the size of image.*

The resulting images shown in Figure 4-2 were obtained from varying the size of the first filter but keeping its sigma constant at 50. The results showed that the filter size equal to the image size seems to work well for most area in the image. The image using the filter 1/2 the image size shows distorted colors in sky. In addition, the image using the 1/2 size filter has higher brightness in the river area than the image with the larger filter size. Comparing the resulting images with the original image, it can be seen that image data were rendered more in brighter areas for the resulting images, whereas most data in the original image were in dark area. This result shows that the resulting images could reveal more details of the image in the dark area than the original.

The absolute luminance (Y) data are also obtained from the low-pass image as described previously. In this experiment, the characteristics of the Gaussian filter used for the second filter were also investigated using two different filter sizes, i.e. the same size as image size and half the size of image size (Figure 4-1). Figure 4-3 shows the results when applying the second filter with two different filter sizes but a constant sigma. Unlike the results for the first filter, there was not much difference present in the resulting images obtained from using different sizes of the second filter. However, the results still showed that the iCAM could improve the quality in image detail of the original.



(a) (b) (c)

*Figure 4-3: The resulting images (a) the original image (b) the image using the larger size of the second filter (c) the image using the second filter with 1/2 the size of image.*

4.1.2 Effects of sigma ( $\sigma$ ).

The sigma is proportional to the amount of blurring in Gaussian filter. In the present study, the sigma for the first and second filters was varied with four values to investigate its impact on image enhancement using iCAM. The four sigma values of filter were 1, 20, 50 and 200. Figure 4-4 shows characteristics of Gaussian filter in the surface plot, when different sigma values were applied with a constant size of filter. It can be seen that sigma has high impact on the shape of filter. The higher the sigma value, the lower the peak of filter data. The filter data were distributed more widely from the center when a low value of sigma was used. This shows that sigma has higher impact on the characteristics of filter than size of filter, due to the fact that it yields much difference on the main contributions of filter.

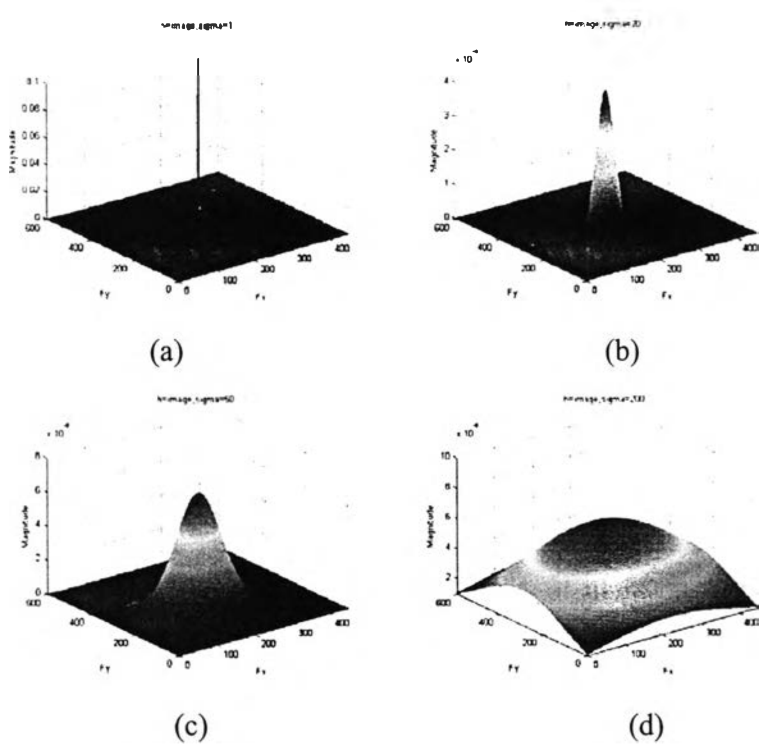



*Figure 4-4: Characteristics of Gaussian filter with a constant size but various $\sigma$ (a) $\sigma$ =1 (b) $\sigma$ =20 (c) $\sigma$ =50 (d) $\sigma$ =200.*

Figure 4-5 shows the resulting images obtained when applying the four filters presented in Figure 4-4 for the first filter in the process of iCAM.

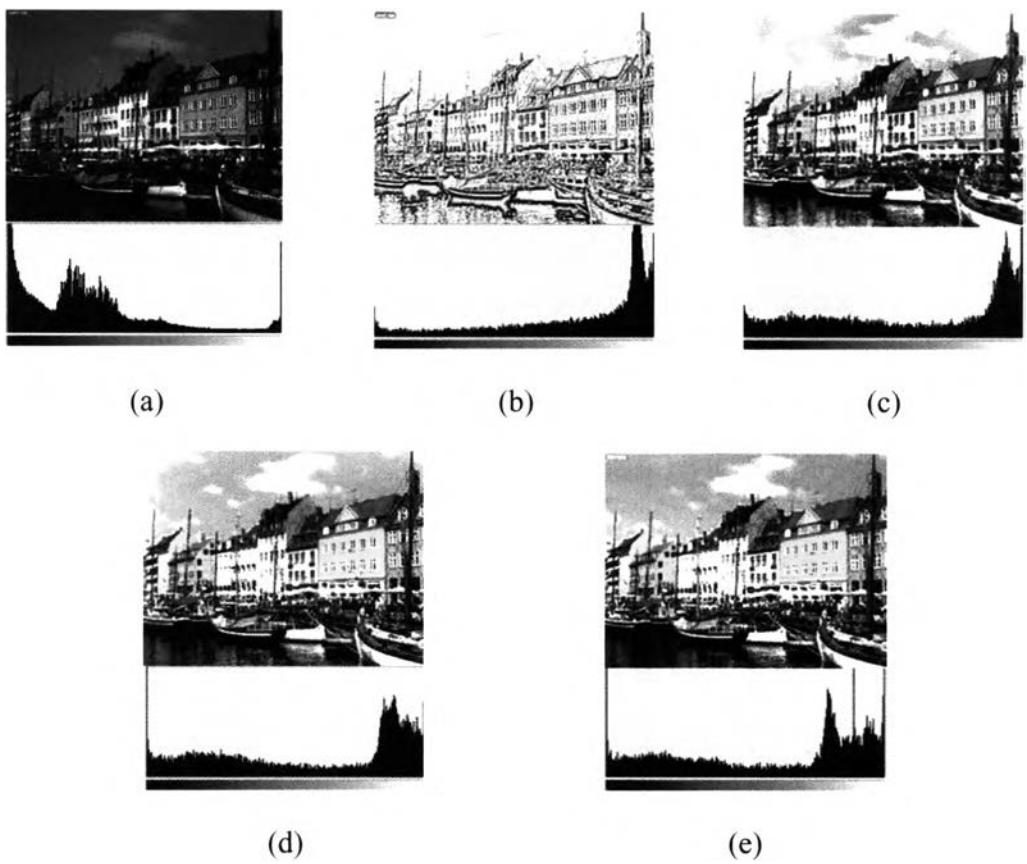



*Figure 4-5: The resulting images obtained from varying the sigma but keeping the size of the first filter constant at the image size (a) the original image (b)* $\sigma$ *= 1 (c)* $\sigma$ *= 20 (d)* $\sigma$ *= 50 (e)* $\sigma$ *= 200.*

The results showed that the sigma values of the first filter had high impact on the performance of iCAM. Image contrast and sharpness increased when low sigma values were applied. For the sigma of 1, the spread of filter data was dense around the center area with high values. When applied this filter to the original image (Figure 4-5 (a)), the resulting image (Figure 4-5 (b)) yielded higher numbers of bright pixels, i.e. the distribution of pixel values shifted from dark to bright direction in image histograms. However, most data were rendered to the extreme, resulting in too high contrast and loss of image detail. The resulting images from higher sigma values showed smoother edges of objects in the images. The image data rendered more properly, as pixel values were distributed throughout the lightness scale. It was found that the appropriate values of sigma were around 50 – 200 because the use of these values could brighten the image while maintaining image detail and pleasing appearance.

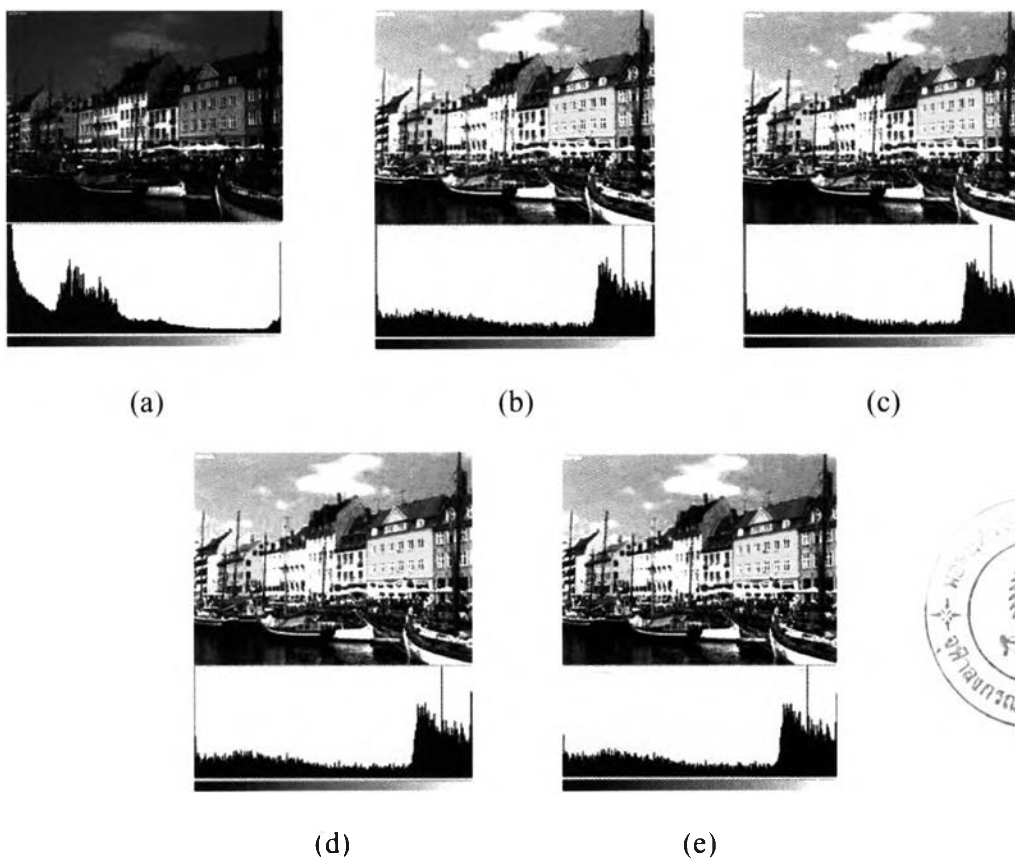





*Figure 4-6: The resulting images from applying the second filter with a constant size of filter but various $\sigma$ (a) the original image (b) $\sigma$ =1 (c) $\sigma$ =20 (c) $\sigma$ =50 (d) $\sigma$ =200.*

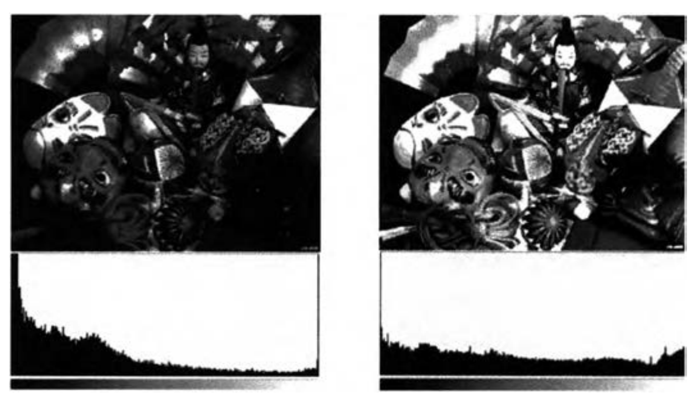
The results obtained from changing sigma values of the second filter are shown in Figure 4-6. It should be kept in mind that the use of second filter accounts for surround luminance adaptation, while the first filter for local chromatic adaptation. Unlike the results for the first filter, not much difference was found between resulting images generated with different sigma values of the second filter. The distributions of image data were very similar for all of the resulting images; they were brighter than the original and had better image rendering.

In summary, the size of filter had little effect on the characteristics of filter. Two different sizes tested yielded very similar results for both first and second filters. Thus, the size of filter used for both filters was in the same size, which was the size of the image. The sigma value of filter had significant impact on the characteristics of filter. For the first filter, it was found that the appropriate values would be around 50 – 200. In the case of the second filter, the sigma of 200 – 500 should have been considered. This is because the values between 1 and 200 showed little difference between the resulting images.

To obtain a good resulting image, the original should be enhanced with iCAM that incorporates appropriate low-pass filters, i.e. a suitable combination of the types of the first and the second filter. The best combinations found for each image are discussed in Section 4.3. From varying the sigma of the first filter between 50 – 200 in conjunction with the sigma of the second filter varying between 200 – 500, a series of images enhanced by iCAM was obtained. Figures 4-7, 4-8, and 4-9 show some examples of resulting images obtained from using good combinations of the first and second filter types for Boat, Japan, and Party, respectively. Note that the sizes of both filters were of the same size, which were the sizes of image size (600 x 450 pixels). It can be seen that the image data of resulting images were distributed more uniformly than those of originals throughout the lightness scale. The numbers of pixel values in bright areas increased while those in dark areas decreased. This reveals that iCAM could improve image detail and brighten the image.

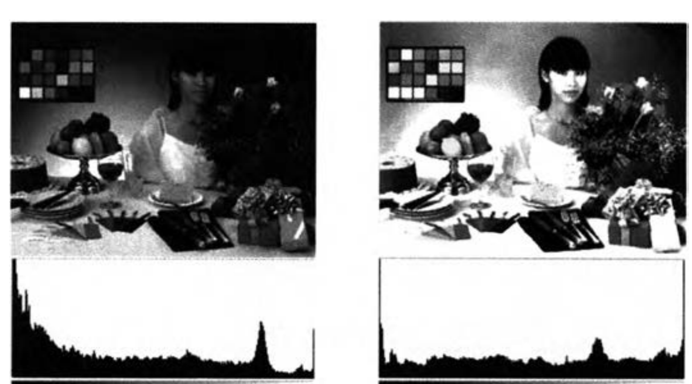
(a) (b)

*Figure 4-7: (a) Original image. (b) Boat image enhanced using iCAM with $\sigma = 50$ for the first filter and $\sigma = 200$ for the second filter.*



(a) (b)

*Figure 4-8: (a) Original image. (b) Japan image enhanced using iCAM with $\sigma = 55$ for the first filter and $\sigma = 500$ for the second filter.*

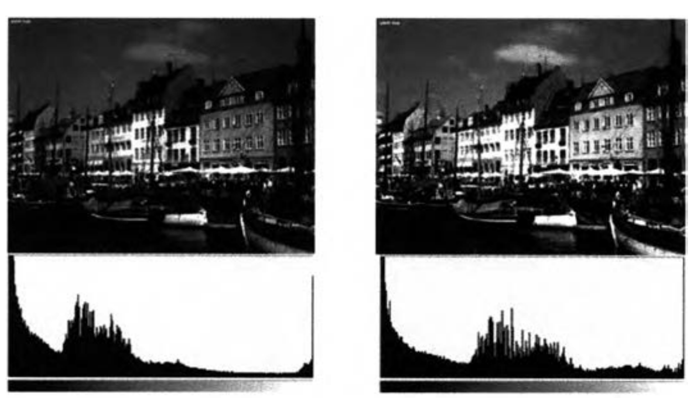


(a) (b)

*Figure 4-9: (a) Original image. (b) Party image enhanced using iCAM with $\sigma = 55$ for the first filter and $\sigma = 300$ for the second filter.*

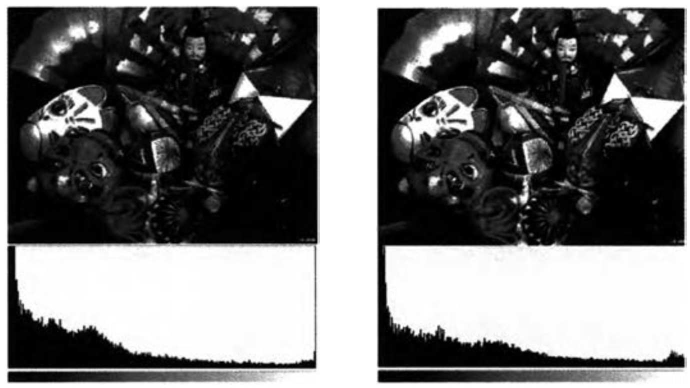
**4.2 Effects of variables in Imadjust**

In Imadjust, the variables low_out and high_out were between 0 and 1, in order to generate an enhanced image that was of good quality. It was found that different sets of variables were needed for different images. However, for all three images (Boat, Japan, and Party) the value of low_out was zero and the value of high_out was between 0.5 - 0.7. These combinations would give good image rendering: brightening images and enhancing image detail. Examples of resulting images enhanced by Imadjust with good combinations of low_out and high_out values are given in Figures 4-10, 4-11, and 4-12 for Boat, Japan, and Party, respectively. It can be seen that the distributions of image data in the original images were improved in the resulting images for all three images.



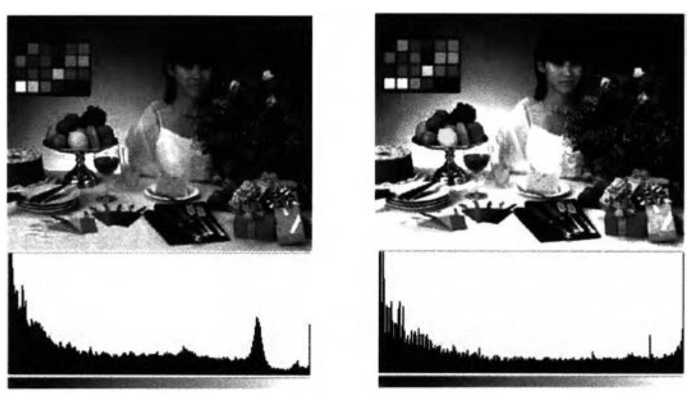
(a) (b)

Figure *4-10: (a) Original image (b) Boat image enhanced using Imadjust [low_out = 0 and high_out = 0.6].*



(a) (b)

Figure *4-11: (a) Original image. (b) Japan image enhanced using Imadjust [low_out = 0 and high_ out = 0.7].*



(a) (b)

Figure *4-12: (a) Original image. (b) Party image enhanced using Imadjust [low_out = 0 and high_out = 0.7].*

### 4.3 Selection of images enhanced with iCAM and Imadjust

The structural similarity index measurement (SSIM) was employed to determine the best images enhanced with each method of image enhancement investigated in this study. The SSIM index indicates the degree of similarity in quality of two images. This study thus used this index to quantitatively compare the quality of each of resulting images with that of the reference image, which was considered to possess perfect quality. The resulting image that yielded the highest SSIM index was considered to have superior quality to other resulting images. This would provide information on the suitable combinations of filters used in iCAM, or of variables used in Imadjust. Note that the SSIM index is between 0 and 1: the higher the number, the higher the degree of similarity. It was found that different types of filters used in iCAM were required for different images. The results are summarized in Table 4-1. For Boat, the image that gave the highest SSIM (0.5784) was the image that was enhanced by iCAM with the first filter using $\sigma = 50$, and $\sigma = 200$ for the second filter. For Japan, the best image (SSIM = 0.5431) was obtained when using $\sigma = 55$ for the first filter and $\sigma = 500$ for the second filter. In the case of Party, it was found that the image yielding the highest SSIM (0.6183) was enhanced using iCAM with $\sigma = 55$ for the first filter and $\sigma = 300$ for the second filter.

*Table 4-1: A summary of filter types used in iCAM to generate images having quality similar to the reference images.*

| | Boat | Japan | Party |
|---|---|---|---|
| 1st filter | Size = 600 x 450<br>$\sigma$ =50 | Size = 600 x 450<br>$\sigma$ =55 | Size = 600 x 450<br>$\sigma$ =55 |
| 2nd filter | Size = 600 x 450<br>$\sigma$ =200 | Size = 600 x 450<br>$\sigma$ =500 | Size = 600 x 450<br>$\sigma$ =300 |
| SSIM | 0.5784 | 0.5431 | 0.6183 |

The results for Imadjust showed that the same variables could be used to generate good quality images for different images. However, to obtain the highest SSIM slightly different values would be applied. Table 4-2 summarizes the variables used to obtain the highest SSIM for each image. It can be seen that the same high_out value (0.7) was used for Japan and Party but a different value (0.6) was used for Boat.

*Table 4-2: A summary of variables used in Imadjust to generate images having quality similar to the reference images.*

| | Boat | Japan | Party |
|---|---|---|---|
| low_out | 0 | 0 | 0 |
| high_out | 0.6 | 0.7 | 0.7 |
| SSIM | 0.7303 | 0.7828 | 0.6132 |

The quality of the original image was also compared to the reference image using the SSIM index. A summary of SSIM obtained from each image is given in Table 4-3. The results showed that the original images had poorer quality than the enhanced images for all image scenes, when compared to the reference images. The images enhanced by iCAM were more different from the reference images than the images enhanced with Imadjust for Boat and Japan. This result reveals that both methods of image enhancement tested in this study could improve the quality of the input images. However, the method of Imadjust could produce images with closer quality to the reference images than the method of iCAM.

*Table 4-3: A summary of SSIM comparing each image with the reference image.*

| | Boat | Japan | Party |
|---|---|---|---|
| Original | 0.5277 | 0.5375 | 0.5500 |
| iCAM | 0.5784 | 0.5431 | 0.6183 |
| Imadjust | 0.7303 | 0.7828 | 0.6132 |

Figures 4-13 to 4-15 show the resulting images enhanced by iCAM and Imadjust, together with the reference image (perfect quality) and the original image (input image) for Boat, Japan and Party. From Figure 4-13, it can be seen that the distribution of pixel values in the Imadjust image was more similar to that of the reference image than that of the iCAM image. The original image had higher numbers of low lightness pixels than the other images. On the other hand, the iCAM image had higher numbers of high lightness pixels, showing a brighter image.

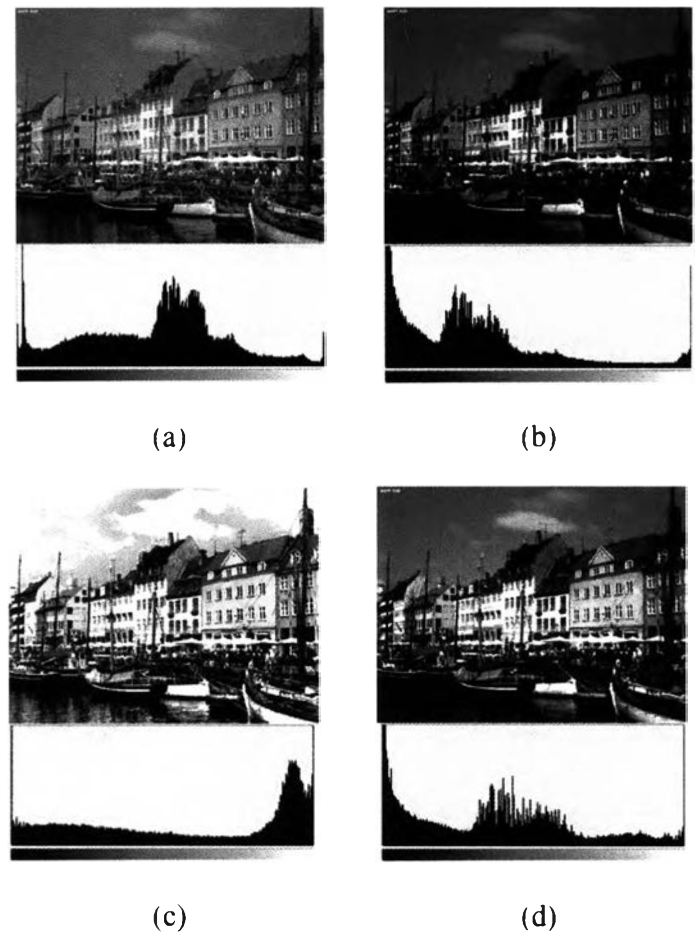



*Figure 4-13: Comparison of Boat (a) the perfect quality image (b) the input image for enhancement, SSIM = 0.5277 (c) image enhanced using iCAM, SSIM = 0.5784 (e) image enhanced using Imadjust (low_out = 0 and high_out = 0.6), SSIM = 0.7303.*

The results for Japan are shown in Figure 4-14. The similar distributions were found between the reference, the original, and the Imadjust image. The distribution of the iCAM image was different in a way that its image data rendered quite uniformly: no high number of pixels in particular area.

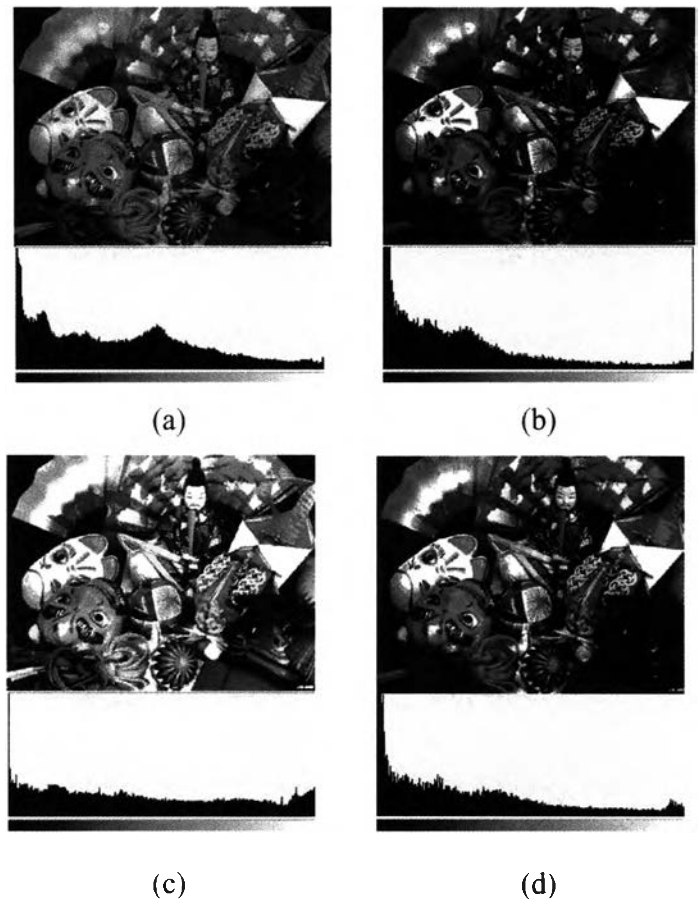
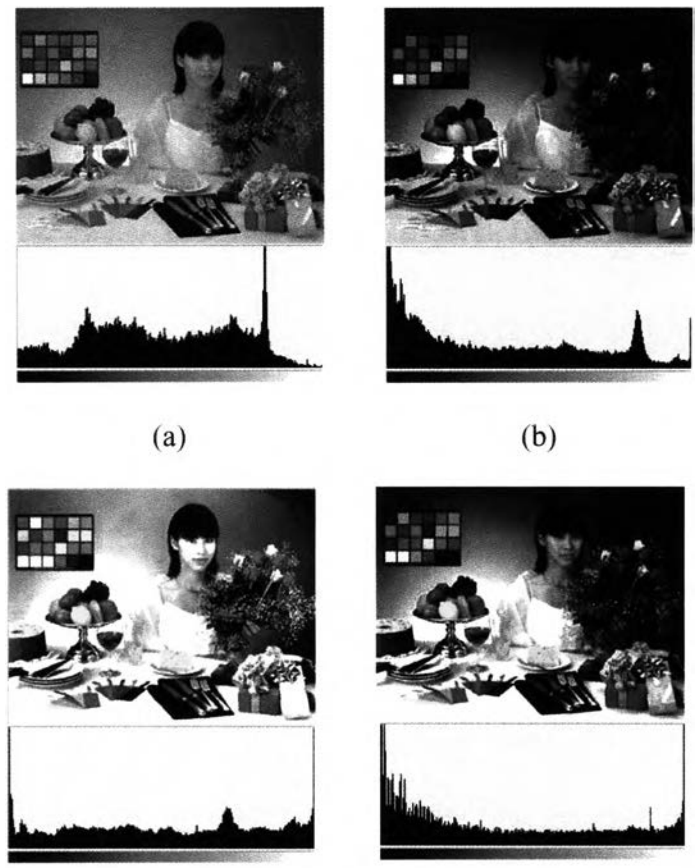



*Figure 4-14: Comparison of Japan (a) the perfect quality image (b) the input image for enhancement, SSIM = 0.537. (c) image enhanced using iCAM, SSIM = 0.5431 (e) image enhanced using Imadjust (low_out = 0 and high_out = 0.7), SSIM = 0.7828.*

In the case of Party (Figure 4-15), the Imadjust image showed similar distribution of pixel values to the input image. Thus, it did not much improve the brightness of the image. As for the iCAM image, the numbers of pixels were approximately the same throughout the entire lightness scale.



(a) (b)

(c) (d)

*Figure 4-15: Comparison of Party (a) the perfect quality image (b) the input image for enhancement, SSIM = 0.5500 (c) image enhanced using iCAM, SSIM = 0.6183 (e) image enhanced using Imadjust (low_out = 0 and high_out = 0.7), SSIM = 0.6132.*

Besides quantitative analysis, the images shown in Figures 4-13 to 4-15 were subjectively compared. The results are given in the following section.

**4.4 Performance of iCAM**

Image quality of the testing images was investigated with two aspects. They were image detail and color appearance. These two aspects are the main contributions to the overall image appearance and image quality. A rank ordering was performed by

20 observers. The experimental raw data are given in Appendix B. These data were analyzed by converting the ranks to preference scores, in which the first rank (considered the best quality) had the score of 3, the second rank = 2, the third rank = 1, and the last rank (the poorest) = 0.

Figures 4-16 to 4-18 show the preference scores for each image averaged from 20 observers for Boat, Japan, and Party. The results of the most preferred rendering varied with images and therefore no average of three images will be considered. There was no clear trend of preference for image appearance of Boat since the results for image detail and color did not agree. As can be seen in Figure 4-16, the mean preferences for color imply that the four images were roughly similar while the mean preferences for detail showed that the iCAM rendering was more preferred than the Imadjust rendering. The Imadjust rendering had the highest mean preference for color of Japan image but the mean preference for detail of image was roughly similar between iCAM and Imadjust rendering (Figure 4-17). The iCAM rendering had the lowest mean preference for both color and detail of Party (Figure 4-18).

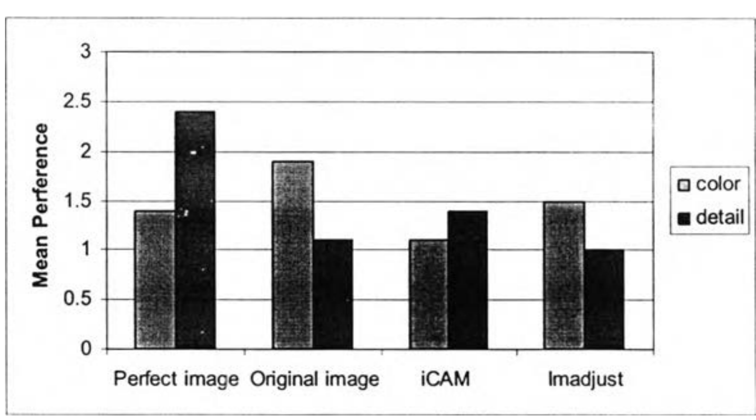



*Figure 4-16: The mean preferences for Boat.*

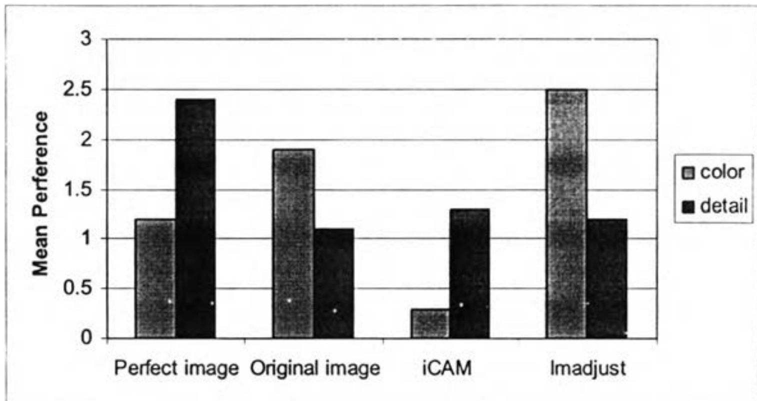



*Figure 4-17: The mean preferences for Japan.*

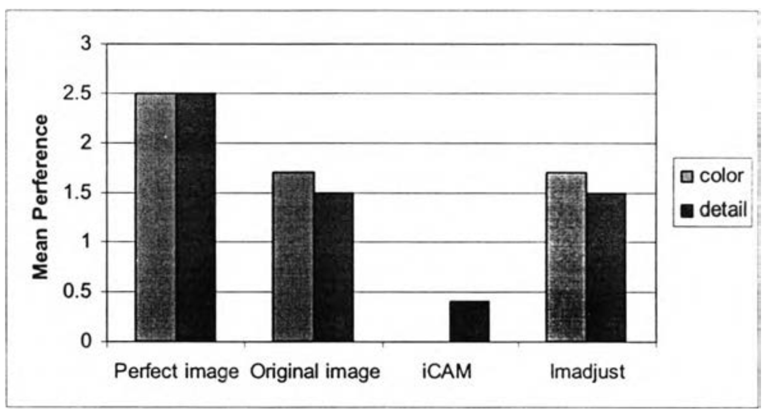



*Figure 4-18: The mean preferences for Party.*

It was found that, as expected, the reference images were most preferred for all aspects and for all image types with only one exception for color of Japan. Japan was an image containing man-made objects which could be of any color. When making judgements for this image, observers preferred more saturated colors. The least preferred images in terms of color were iCAM for all image types, especially Party where it was always put in the last rank for all observers. This is because iCAM produced too bright images with fading colors. However, in terms of image detail iCAM gave the second best performance for two out of three images, i.e. Boat and Japan. These results did not agree with the SSIM results that showed that SSIM of iCAM were lower than those of Imadjust for both Boat and Japan. This is due to the fact that SSIM obtained from the overall quality of images, whereas in the visual assessment observers were instructed to focus on the image detail only. Since iCAM did not perform well for color, this lessened the SSIM index. In the case of Party, iCAM gave worst performance for both color and detail. This could be because of the characteristic of the image. Party was different from the other two images in a way that it had more of highlight areas. iCAM worked well in enhancing detail in shadow areas but failed to enhance lost-detail in highlight areas. This can be seen from the absence of texture on fan in Figure 4-14 (c) and the absence of the line on building in Figure 4-13 (c). For the shadow areas, it can be seen from the presence of fabric texture in Japan in Figure 4-14 (c).

In conclusion, the use of iCAM with appropriate filters could improve quality of the input images in terms of image detail. Image data of iCAM images spreaded out from shadow to highlight on the lightness scale. Different types of filters were needed for different image types. For low-key images (containing mainly shadow areas), a high value of sigma for the second filter might be applied. The sigma of the first filter should be around 50, while that of the second filter is much higher, varying between 200 – 500. The low sigma value was required for the first filter because this filter accounted for local chromatic adaptation; low-sigma values would result in dense distributions of filter values around the center with its high peak. With this characteristic of filter, each pixel in the image after convolution was largely changed, resulting in better image rendering. The second filter accounted for surround luminance adaptation; thus, the image data should not be largely modified. The high sigma values were then applied.

The size of filters had little effect on the model's performance. The image size is recommended to use as the filter size for both filters. However, the results showed that iCAM did not perform well in terms of color. Even the input image, which was considered to possess poor quality, showed better performance. This was because iCAM produced low saturated colors.