Image Quality Enhancement and Evaluation for Digital Displays

Kyoung Tae Kim, Byong Tae Ryu, Seul Ki Jang, Yu-Hoon Kim, Qiao Song Chen, Choon-Woo Kim
School of Information and Communication Engineering, Inha University, Incheon, 402-751, Korea
TEL:82-32-860-7401, e-mail:cwkim@inha.ac.kr.

Abstract

Image quality is one of the most important factors affecting the performance of digital displays. This paper introduces various digital image processing techniques commonly applied to digital displays. They include preferred color correction, tone reproduction, and frame rate conversion. Also, issues related to image quality evaluation are addressed.

1. Introduction

Image quality becomes one of the most important factors affecting performance of digital displays. Display manufactures have introduced so called imaging engine to differentiate their image quality. Imaging engine is a family of proprietary techniques designed for image quality improvement. These techniques can be divided into two classes; display type dependent and independent techniques. The former represents image quality enhancement methods to solve quality related problems unique to the given display type. For example, dynamic false contour reduction and smooth tone reproduction in dark areas are unique to PDPs. LCDs have their own image quality issues such as motion blur, viewing angle, and contrast ratio. Display type independent techniques include color correction, noise removal, and image resizing, etc.

Digital displays can be categorized based on their applications. Most popular applications include computer monitors, television, information display and mobile devices such as cellular phone, pocket PCs, PMP(portable multimedia player) and navigation devices, etc. Requirements for image quality depend on the applications. For example, variety of viewing illuminations should be carefully considered for developing image enhancement techniques for mobile applications. However, viewing conditions are assumed to be fixed for television and computer monitor applications. Also, size of memory resources and power consumption of image enhancement techniques are quite limited for mobile applications.

In order to investigate the performance of image quality improvement techniques, evaluation of image quality is necessary. It can be accomplished based on human visual tests or quantitative analysis. Human visual tests are very effective but time-consuming. Thus, quantitative methods that are highly correlated with the results of human visual tests are desirable. Evaluation of image quality can also be utilized to prioritize the research activities for image quality improvements on displays.

In this paper, image quality enhancement techniques that are frequently utilized for digital displays such as LCDs and PDPs are introduced. Also, issues related to the evaluation of image quality are addressed. In sections 2 and 3, display type independent/dependent techniques are reviewed, respectively. In section 4, issues related to image quality evaluation are described. Finally, the conclusion is addressed in section 5.

2. Display Type Independent Image Enhancement Technique : Color Correction

Image enhancement techniques that can be applied to various types of displays may include color correction, noise removal, and image resizing, etc. Among these techniques, color correction techniques are introduced here. From the manufacturer's point of view, a given model of displays should have consistent color reproduction capability. Some of the manufacturers try to maintain color reproduction consistency for various models and even regardless of display types.

For computer monitor applications, colorimetric color correction that minimizes color differences between original and reproduced colors is desirable. For example, colorimetric reproduction may be applied for computer monitors to be matched with standard sRGB color space. In this case, if display gamut is different from that of sRGB, gamut mapping technique needs to be applied.

However, for television applications, preferred color reproduction may be recommended. Objective of preferred color reproduction is to produce images that are pleasing to observers. It modifies input memory colors such as skin, grass and sky to the preferred color coordinates[1]. Figure 1 shows general procedure for the preferred color correction. Information on color preference should be obtained in advance. It can be done by off-line human visual tests. Human subjects are asked to choose or modify the memory colors freely to determine coordinates of preferred colors[2]. Of course, memory color preference depends on age, gender, and races.

On-line procedure for preferred color reproduction can be summarized as follows; Areas containing skin, grass and sky are extracted from the image. Figure 2 shows an example of area detection. Figure 2(a) represents an original image before area extraction. Figure 2(b) represents an example of extraction result. Extraction can be performed in various color spaces such as YC_bC_r, $L^*a^*b^*$, XYZ, or HSI. Pixels belonging to the predefined shape of ellipse, rhombus, or square in the one of the aforementioned color space are determined as memory colors. The predefined shape affects the extraction performance. Instead of choosing pixels in the predefined areas, extraction of memory colors can be regarded as a pattern classification problem. In this case, statistical classifier or neural network based approaches are applied for the extraction[3].

Preferred color correction is then applied only to the pixels in the extracted areas. Detection of areas for correction may not be perfect. As an example, it can be noticed in Figure 2(b) that portions of neck area were not correctly detected as skin. Thus, undesirable contours may appear in the boundary between the detected and undetected areas. These contours should be minimized during the correction.

Extraction and correction should be performed on-line. In other words, these two steps should be performed at every frame within 1/60 sec in the case of NTSC.

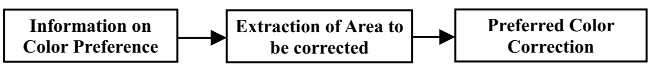
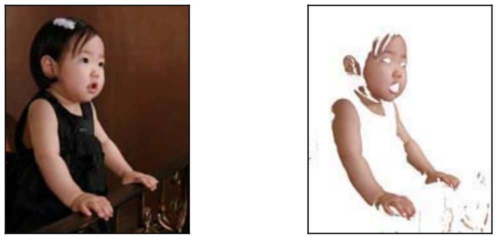


Fig. 1. Procedure for preferred color correction.



(a) before extraction (b) after extraction

Fig. 2. Example of preferred color detection

3. Display Type Dependent Image Enhancement Techniques

In this section, image quality enhancement techniques that are frequently utilized for digital displays such as LCDs, PDPs, and mobile devices are introduced.

3.1 Tone reproduction in dark areas for PDP

Unlike CRT, luminance of the PDP has linear characteristics within normal operating range. Gamma correction is applied for PDPs to generate images being equivalent to those on the CRTs. In dark areas (or lower gray level ranges), slope of the desired luminance curve has very low value. When gamma correction is applied, number of displayable gray levels in dark areas is significantly reduced. This reduction in the number of displayable gray levels in dark areas causes undesirable false contours or loss of details.

Most popular techniques applied to achieve smooth tone reproduction in dark areas are error diffusion or dithering. Most of previous works proposed to utilize either error diffusion or dithering to improve tone reproduction in dark areas[4,5]. Recently, combination of dithering and error diffusion was proposed to further refine tone reproduction performance[6]. In [6], fractional parts of gray levels to be displayed are represented by 8 bit numbers. Error diffusion is first applied to lower 5 bits of the fractional parts. Result of error diffusion is added to the remaining 3 bits. Dithering is then applied to the updated 3 bits of factional parts.

Performance of tone reproduction in dark areas can be evaluated by the homogeneity of minor pixels in a given frame and between frames. Degree of flickering and undesirable patterns in moving images need to be examined. Also, in order to reduce the visibility of minor pixels, they should be turned at different pixel locations over consecutive frames.

3.2 Dynamic false contour reduction for PDP

PDP represents gray levels by the pulse number modulation. It is suitable for representing gray levels of a still image. However, in the case of a moving image, it causes a problem. When an object moves, human eye follows the motion. Brightness perceived by human vision is determined by integrating the light emission over time in the direction of motion. When light emission periods for neighboring gray levels are far apart, a false contour would appear. Since it is observed only on moving images, it is called as dynamic false contour.

Various techniques have been proposed to reduce the dynamic false contours. These include the addition of equalizing pulses, the compression of light emission time, and error diffusion or dithering. Among these techniques, error diffusion or dithering are most frequently utilized[7]. General procedure can be summarized as follows; Pixels that would generate dynamic false contours are estimated first. Their gray levels are modified so that they would prevent or minimize the dynamic false contour. In order to preserve original tone levels, gray levels are compensated by applying error diffusion or dithering techniques.

Dithering may generate undesirable fixed patterns. In order to reduce the fixed pattern due to the ordered dither, stochastic mask such as blue noise mask could be utilized. As an alternative, time varying or region dependent mask could also be applied. Performance of error diffusion depends on the value of weights and position of neighboring pixels for error propagation. Also, thresholding method and processing sequence affect the performance.

3.3 Frame rate conversion for reduction of motion blur in LCD

Motion blur due to slow response time is one of image quality related issues for LCDs. Frame rate conversion(FRC) is one of the techniques to reduce the motion blur. FRC has been widely studied for the coding of video sequences. Also, it can be applied to improve visual quality of terrestrial digital multimedia broadcasting on cellular phone with the built-in projection functionality[8].

Motion compensated FRC method has been a popular choice for reduction of the motion blur. Displacement of objects between successive frames is estimated and the predicted frame is interpolated by the estimated motion vectors. Block matching algorithm has been widely utilized for the motion estimation. Adaptive block size and search window can be employed depending on the degree of motions to reduce the computational complexity.

It is common to have right to left moving subtitle carrying news or weather information at the bottom of the frame. When motion vectors are incorrectly estimated, results of FRC in the moving subtitles may appear quite annoying. In order to improve the accuracy of motion vectors, motion vector refinement techniques can be applied.

3.4 Color correction of camera images for cellular phone

Most of cellular phones have built-in digital camera. Two types of illumination should be considered for color correction of images captured by the built-in digital camera; illumination during picture taking and viewing illumination. Illumination during picture taking can be compensated by automatic white balancing techniques. Objective of automatic white balancing is to generate consistent colors regardless of illuminant utilized during picturing[9].

Gray world assumption is often utilized for the automatic white balancing techniques. It works well for most of images having variety of color contents. However, it is not suitable for images with dominant single color contents. Effect of viewing illumination can be compensated by modifying image to be displayed based on the type of estimated viewing illuminants[10].

Due to the limitation on the size of memory resources and power consumption, color correction is often performed using simple linear transformation. After color correction by the matrix multiplication, additional preferred color reproduction is applied for the high-end cellular phones to further improve displayed image qualities[11].

Some of the displays for cellular phone are incapable of displaying 24 bit (8 bits per color) color images. Due to this limitation, banding can be noticed in smooth tone transition area such as cloudy sky. In order to minimize the undesirable bandings, multi-level error diffusion or dithering can be applied.

4. Image Quality Evaluation

In order to investigate the performance of image quality improvement techniques, evaluation of image quality is necessary. Evaluation of image quality can also be utilized to prioritize the research activities for quality improvements. Various works have presented performance evaluation procedures for individual enhancement techniques. For, example, performance of error diffusion or dithering can be evaluated by the following criteria; reproduction of gray levels, edge production, visibility and homogeneity of minor pixels, degree of noises, processing time, size of memory resources, and slow response, etc. However, literature on overall evaluation of image quality is scarce.

Image quality on displays is determined by human observers. Thus, it is natural to say that evaluation of image quality should be accomplished based on human visual tests. Human visual tests may be performed based on the category judgment, pair comparison, or triplet comparison[12]. However, these human visual test methods are quite time-consuming. Also, visual quality evaluation of moving images has not been well-defined yet. Quantitative image evaluation methods can be utilized as an alternative to human visual tests. However, results of quantitative methods should be highly correlated with those of human visual tests.

In order to quantitatively evaluate image quality on displays, characteristics of imaging engine should be considered. Instead of input color coordinates, output color coordinates on displays should be utilized in quantification. In other words, color transformation model between the input and measured output color coordinates for a given display is determined in advance. Static characteristics such as coordinates of primaries, gamma characteristics and color temperature of white can be reflected by this transformation model.

Some of the imaging engines adopted scene dependent enhancement techniques such as dynamic contrast enhancement. In this case, the same color input to the displays may result in different output color depending on the contents of image frame. Thus, quantification methods should reflect the scene dependent techniques by their simulations. Also, user adjustable control parameters should be fixed at factory setting.

Most commonly used quality metrics include sharpness, contrast, naturalness, colorfulness, and noise, etc. First of all, it is desirable to standardize quality metrics and their definitions. Also, the aforementioned quality metrics depends on the image contents. Well-defined test image selection is very important for image quality quantification. Another issue related to image quality evaluation is the normalization of scale values. Value of each metric should be normalized to represents JND (just noticeable difference) for fair comparison[12].

The aforementioned quality metrics are mutually correlated. For example, noise and sharpness are somewhat correlated. However, unified quality metric representing overall image quality is desirable. It can be formulated as a linear/non-linear combination of individual quality metrics.

5. Summary

Recently, image quality becomes one of the most important factors affecting performance of digital displays. This paper introduced image quality enhancement techniques that are frequently utilized for digital displays such as LCD, PDP, and mobile devices. They include preferred color correction, tone reproduction, dynamic false contour reduction, frame rate conversion and color correction for cellular phone displays. Also, criteria for quantitative image quality evaluation are addressed. It is highly desirable to develop standardized procedures of quantitative evaluation techniques for still and moving images on displays.

6. References

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