43.1: Image Enhancement for Reflective Displays

Petri Nenonen, Jukka Yrjänäinen
Nokia Research Center, Tampere, Finland
P.O. Box 100, FIN-33721 Tampere, Finland

Abstract

The reflective and transflective LCD technologies offer attractive solutions for color displays that are used in handheld devices. These technologies make possible to obtain a full color display with low power consumption by using ambient illumination as light source. When there is not enough ambient light an internal light source can be used. The current generation of displays has quite adequate quality for viewing color images in some conditions, but they still have also some insufficient properties. The color gamuts and contrast ratio of the displays are small and dependent on the illumination. We have researched how the properties of the displays affect imaging applications and how those can be overcome by using image processing means. We are focusing on image enhancement algorithms, which we have tested under different viewing conditions. Especially algorithms that are effectively implementable are interesting. In this case the target is to increase the visibility and the subjective quality of the image on the display as opposed to reproduce the originally intended appearance exactly. The achieved results show that the perceived image quality and the usability of the display can be enhanced significantly using image enhancement techniques.

1. Introduction

Digital imaging applications have emerged into current generation of handheld devices. An example of this kind of an application is a photo viewer, which may in addition to basic image viewing operation, include image adjustment, editing or enhancement features. This type of a complete imaging application requires full color display. The users expect to see the image with an adequate quality, which means fairly high contrast and brightness together with vivid colors. The quality is often compared with the image quality on a transmissive LCD or a CRT based display, which are widely used as monitors with PCs.

From power consumption, size and weight viewpoints reflective displays offer an attractive solution for the display of a portable handheld device [1-3]. The data on the display is visible always when the amount of illumination is sufficient. Because many devices have to be usable also in dark conditions a plain reflective display is not the ultimate solution. This problem has been solved by adding a lightning device to a reflective display. Another very attractive solution is the transflective display [1]. The transflective display can operate both in reflective mode and in transmissive mode with a backlight. The display is usable in large variety of viewing conditions, such as under bright sunlight and in totally dark room. The transmissive properties of the latest transflective displays are approaching the level of transmissive LCDs. However, the reflectivity is not yet at a satisfactory level. Therefore also the contrast ratio and color saturation requires some improvement [3, 4]. The color gamuts of transflective displays are quite small compared to typical gamuts of transmissive LCDs or CRTs. Displayed images seem to have poor contrast and faint colors. We have researched how these properties affect the imaging application requiring high quality full color display. We also show some examples how the insufficient capabilities of the display can be overcome by using simple effectively implementable basic image processing algorithms. We are focusing on transflective displays, but due to very similar features the results are applicable also to other type of reflective display technologies.

2. Display

In a reflective LCD the ambient illumination is reflected to the viewer with a reflector behind the display. The amount of reflected light is adjusted by a liquid crystal layer over the reflector. Colors are produced by using interlinked color filters. The display can also be illuminated with an additional front lightning device for viewing under dark illumination conditions. In transflective displays some amount of light coming behind the reflector can pass through it. Therefore a backlight can be used for illuminating the display. Both reflective and transflective displays have similar characteristics from imaging viewpoint.

When a reflective or a transflective display is designed the transmittance, reflectance, contrast ratio and color purity need to be balanced [1]. When the display is used for displaying colored graphics, such as menu structure of a user interface, the color saturation and purity is not so critical issue. The graphics can be designed so that the properties of the display are taken into account. A sensation of a pleasant color display can be obtained with only a few colors. In this case the contrast and color saturation of the few selected colors are the main properties affecting the quality of the display. Higher demands are raised when natural images are shown [5]. A display for the imaging use requires full color, high saturation and sufficient color contrast capabilities in addition to adequate luminance contrast ratio. Because different types of images come from various sources, the display has to be able to show image data that can have huge variation in color content and also in spatial features. Practical tests show that the current generation of transflective displays is capable of showing certain types of images in certain conditions with quite satisfactory quality. These images usually have quite high contrast and saturation or color contrast. The suitable conditions are very bright illumination with flat spectral characteristics or then a sufficiently dark environment, in which the backlight is bright enough. However, these are special use cases and in other conditions improvement is required.

The most important property of the display for color imaging applications is the size and shape of the color gamut. In reflective displays the gamut is dependent on the ambient illumination. Examples of chromaticities that define color gamuts of a transflective display operating in reflective mode are shown in figure 1. The color gamut of a typical CRT is shown for comparison. The largest gamut corresponds to the CRT, the smallest one is measured from the transflective display under incandescent lightning and the third one under sunlight.

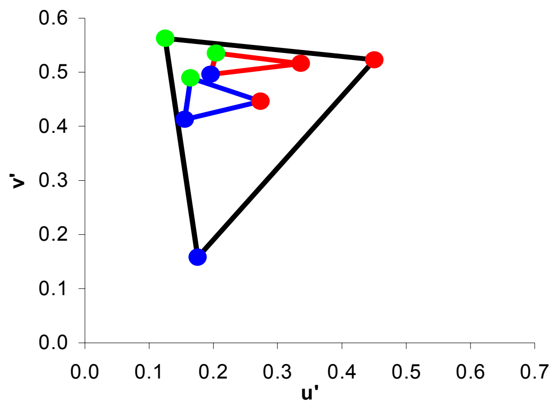

Figure 1. Color gamuts of a CRT and a transflective display under different illumination conditions.

It can be seen in figure 1 that the color gamut of the measured display is small compared to the gamut of a CRT monitor. Most of digital images coming from arbitrary sources are optimized to be viewed on a CRT monitor. During this research we use images that are within a satisfactory level compliant with the sRGB color space [6]. Images in this color space are well suitable to be viewed on a typical CRT monitor. Ideally the monitor should be calibrated to the color space of images or images transformed to the monitor color space [7]. However, in practical case some variation in appearance of images can be tolerated and a typical non-professional user of imaging devices is not performing the calibration. Therefore sRGB images are expected to have an adequate quality also on an imaging device with a reflective display. However, because the color gamut of a transflective display is typically smaller than CRT gamuts, many images shown on the transflective display have low contrast, color contrast and saturation. The color gamut of the display is also dependent on the type and amount of the ambient illumination. This means that the appearance of images varies significantly in different viewing conditions. In general, images that utilize whole color gamut are well visible, but images that use only a small portion of it suffer severely from the insufficient color and contrast capabilities of the display.

A display simulator can be built up based on the measured display chromaticities. The measured chromaticities together with the black and white points can be used to compute a color space transform between the color space of the display and any other known color space. The simulation is achieved by processing the original image with this transformation. The result image can then be viewed with any calibrated monitor. Because we were testing with sRGB compliant images, the transformation between color space of the display and sRGB is used. Monitors that are used for observing the results should be sRGB calibrated. The sRGB defines nonlinear response and also the simulated display has a nonlinear response. These nonlinearities have to be taken into account in the simulation. The nonlinearity of sRGB is made for compensating the exponential response of CRT monitors [6]. Typical transflective displays have a S-shaped response curve. Although these features have been modeled, the simulated image is not an exact reproduction of the image seen on the display. For example, the display has different pixel size and usable viewing angle than the monitor. Also the viewing conditions affect the results significantly due to the adaptation of the human visual system to the ambient illumination [7]. However, the simulation can be used for the visualization of results. The simulation is giving guidelines on how images appear on the display from color and contrast viewpoint. It is also used for presenting the results of image processing algorithms. An example simulation is shown in figure 2. The simulation is computed for a transflective display that operates in reflective mode under fairly dim ambient illumination. Lower contrast together with faint and hue shifted colors are clearly seen in the simulated image.

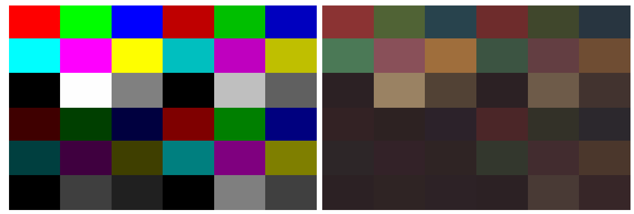

Figure 2. Display simulation. Left half is the original image. Right half is the simulated appearance of the image viewed on a transflective display under dim ambient illumination.

3. Image Processing

The capabilities of displays can and have been improved with display technology specific solutions [3, 4]. Each generation of reflective and transflective displays is a bit better than the previous. However a quality that satisfies all requirements of digital imaging applications in all viewing conditions is not yet available. Therefore some improvement in perceived image quality can be obtained by using image processing means. The image itself is the core part of the imaging chain and therefore changing it will also produce changes in the perceived quality.

In general, producing colors of an image with a tight control on how they are appearing can be considered to be a color management problem. In color management systems colors are processed and transferred from one device to another so that the originally intended appearance of the image is achieved [7]. For example, in the display specific case this means that an image seen on the target display has very close the same appearance than on a calibrated reference monitor. Unfortunately an accurate color management is quite complex task and in case of transflective displays it is also impossible, which can be clearly seen from the very different gamut sizes in figure 1. The transflective display is capable of producing only a minor part of the required color gamut. Colors outside gamut cannot be presented with the display. Another problem increasing the complexity of the color management approach is that the color gamut is illumination dependent.

Because the color gamut of the display is small and dependent on the ambient illumination, the displayed colors will always look unnatural, except in those cases when the color gamut of an image happens to be completely inside the color gamut of the display and color management solutions can be applied successfully. Another applicable solution is the utilization of the color gamut as effectively as possible, but without trying to restore the colors exactly. In other words, the subjective quality of an image can be improved using image enhancement instead of exact color management. It has been also shown that it may be more advantageous to try to get more colorful images than perfectly natural images [8]. With images that fully utilize their color gamuts maximum utilization of display gamut means simply direct mapping from image color space to display color space. In this case the output colors are shifted in hue, saturation and brightness when compared to the intended output colors. If the image is processed with image enhancement algorithms prior displaying it, these and other features can be modified. Because of the direct mapping the processing is done in the display color space, which makes the processing to be display specific and the display specific features can be taken into account.

A simple way to increase the visibility of an image is color gamut stretching. The basic idea is to expand the color gamut of an image so that the available color gamut of the display is utilized effectively. The principal idea is shown in figure 3. The direct lines are borders of the color gamut of the display. The light gray area is the original color gamut of the image. The dark gray area is the expanded color gamut.

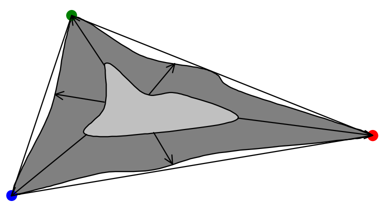

Figure 3. Color gamut expansion.

An example of a practical and simple method for the color gamut expansion is the well known contrast stretching [9, 10]. The basic contrast stretching is often also known as histogram stretch. When the algorithm is applied to RGB color components separately it ensures that each color component uses the whole available dynamic range. These types of algorithms have been used for image adaptive automatic contrast enhancement in many image processing products. Sometimes the algorithms are applicable and produce good results, but they also often decrease the quality of images that are viewed on a good quality monitor. The color saturation and hue are changed and the images may look unnatural. Quantization errors may also become visible, because in practical cases the original image has a limited bit depth. The strength of algorithms can be limited but it is difficult to achieve the right balance between a visible enhancement and an adequate robustness. However, when the enhanced images are viewed on a low contrast display, the properties of the display tend to hide the harmful effects. The balance between the enhancement power and the robustness can be found. The result image is more clearly visible and more colorful than the original but the increased unnaturalness of the enhanced image is only rarely visible. A more effective variation of histogram stretch is the histogram equalization [9, 10]. The strength of the equalization can be limited with many modifications [11]. The limitation can be tuned for the display specific case. Therefore general contrast enhancement algorithms based on modified histogram equalization or stretching are very beneficial.

The presented histogram stretch based gamut stretching method can be applied on each color component separately. In this case the color gamut stretching is done towards the directions of base vectors of the color space, which means that color contrast of image is enhanced but not necessarily the luminance contrast. The luminance component can be processed in a similar manner. This requires a color transformation that separates the luminance component from the color components.

Saturation increase methods are is quite usable in color image processing, because increasing the color saturation tends to increase the perceived quality even when the naturalness of the image is reduced [8]. This is true especially with transflective displays, which inherently produce low saturated images. Due to this it is beneficial to apply a saturation increase algorithm together with the other gamut stretching algorithms. Especially if only luminance signal is processed, a controlled amount of saturation increase is very advantageous. Best results are achieved with saturation increasing methods that are adaptive to the saturation of the original image.

The gamut stretching algorithms process images globally from spatial viewpoint. An example of spatially local processing is sharpening algorithms. These algorithms emphasize subjective sharpness and visibility of edges in an image. This means also increasing the local contrast around the edges. A typical example of sharpening is the unsharp masking algorithm [9, 10]. When sharpened images are viewed on a high quality monitor the drawbacks of the unsharp masking algorithms are visible. These drawbacks include ringing artifacts and noise enhancement. Therefore the gain of unsharp masking algorithm has to be kept quite low. Transflective displays that are suitable for the mobile use have often quite small pixel size. This reduces the size and disturbance of the ringing artifacts. Also the lack of contrast reduces the visibility of ringing effects and noise. At the same time the increased local contrast makes details and objects in the image more clearly visible.

Saturation increasing algorithms combined with componentwise or luminance stretching expands the color gamut of the image to many directions as shown in figure 3. The gamut of the image can be stretched to fill more completely the available color gamut also in a numerous other ways. Also spatially adaptive local methods can be used. Sharpening was given as an example of spatial enhancement algorithm. The category of global and local feature, contrast and color enhancement algorithms is wide [9, 10]. Image enhancement algorithms and methods for reflective and transflective displays can be selected or combined from those in many ways. From display specific viewpoint algorithms that compensate the insufficient properties of the display are beneficial. At the same time it is important to select the enhancement methods and their parameters so that the properties of the display and its prevailing state hide the possible artifacts caused by the enhancement.

4. Results

We have tested different image processing methods with various types of images that were viewed on transflective display modules. It was found out that even simple gamut stretching and color contrast and saturation enhancement algorithms improve the subjective image quality. Properties of the display hide the unwanted effects and artifacts. A low contrast display does not demand as high robustness as a high quality monitor. However, some adaptation to images and features of the display is still required. It is beneficial to limit the strength of the algorithms so that images that already are suitable for viewing on a low contrast display are not processed. This guarantees that the naturalness of images is not altered in a disturbing amount.

Examples of achieved results are show in figure 4. The enhanced images are processed with histogram stretch based gamut expansion algorithm combined with an additional saturation increase and sharpening. The results are shown using the previously presented display simulation method. The simulated case is a transflective display in reflective mode under relatively dim lightning. This is the most difficult use case. The first column contains the original images, the second one the original images viewed on a transflective display and the third one the enhanced images shown on the same display. The first row contains an image that originally has rather good contrast. The original image on a second row has a natural appearance and quite good reproduction of the actual scene and of the illumination conditions during the capture, although subjectively it may seem to have a bit reduced contrast. The image on the last row has low contrast and underexposed appearance. It is seen in the example images that originally good image is not changed too much. The properties of the display are utilized effectively. Because those cannot be exceeded, enhancing the image more would increase the risk of introducing additional artifacts. The other two images are enhanced remarkably. The contrast and color appearance is clearly more pleasant in the enhanced images. At the same time also the original appearance of the images is approached, although exact color management was not the goal. With this type of enhancement the usability of the display is increased significantly.

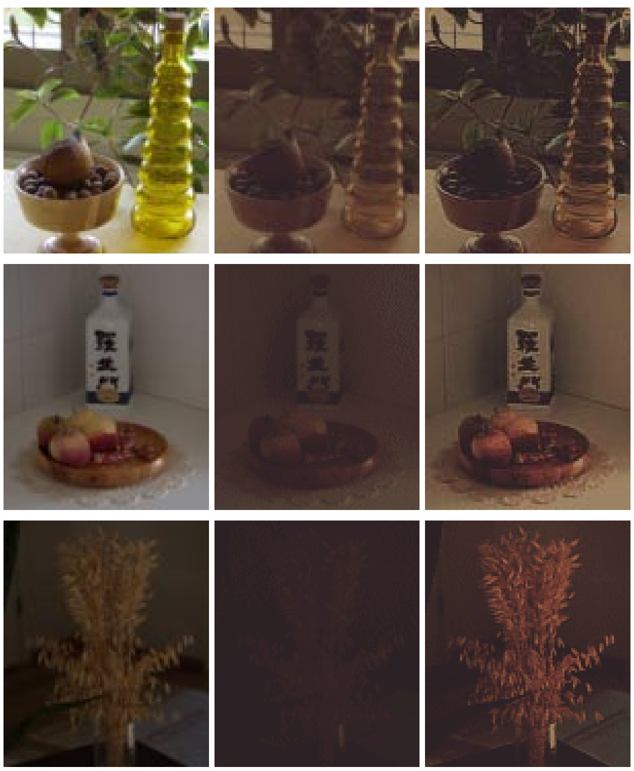

Figure 4. Result images. The first column shows the original images. The second one contains the original images viewed on a simulated transflective display. The third column consists of enhanced images viewed on the same display.

5. References

[1] Wu, S., Yang, D., Reflective Liquid Crystal Displays, John Wiley & Sons, Ltd., 2001

[2] M.E. Becker, J. Laur, J. Neumeier, "Electro-optical Characterization of Reflective LCDs," SID 01 Digest, SID, 2001.

[3] Y. Huang, F. Ko, H.D. Shieh, "High Brightness Reflective Color STN-LCD Using a Multi-Directional Asymmetrical Microlens Array Light Control Film" SID 01 Digest, SID, 2001.

[4] A. Masaki, T. Uesaka, Y. Kumagai, K. Kaminade, T. Toyooka, Y. Kobori, "Twisted-Nematic Compensator for Reflective Color NB-STN-LCDs with a Single Polarizer," SID 01 Digest, SID, 2001.

[5] E.H.A. Langendijk, I. Heynderickx, "Optimal and Acceptable Hue Ranges for Display Primaries," SID 01 Digest, SID, 2001.

[6] IEC, Technical Committee No. 100, Project Team 61966, "Default RGB colour space - sRGB," IEC, 1998.

[7] G. Sharma, M.J. Vrhel, H.J. Trussel, "Color Imaging for Multimedia," Proceedings of the IEEE, vol. 86, pp. 1088-1108, June 1998.

[8] H. de Ridder, "Image Processing and the Problem of Quantifying Image Quality," ICIP 2001 Proceedings, IEEE, 2001.

[9] Gonzalez, R.C., Winz, P., Digital Image Processing, 2nd edition, Addison-Wesley, 1987

[10] Jain, A.K., Fundamentals of Digital Image Processing, Prentice-Hall International, 1989

[11] Nenonen, P., Television Picture Contrast Enhancement Based on Histogram Equalization, Tampere University of Technology, 1996.