Television Image Quality Enhancement Using Observer Interactive Tool

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Abstract

This study tried to extend applicability of colour imaging technologies, e.g. gamut mapping, gamut extension, image quality, to enhance image quality of Plasma Display Panel (PDP) television in terms of recovering mismatches between television standard broadcasting signal and display system. To do this aim a user-friendly interactive tool with four different functions was developed for television ASIC designers. Colour –matching and pleasantness performance of newly derived method using the developer tool was evaluated by psychophysical experiment and traditional quality control process. Six different test images including two moving video clips were used in the experiment.

Introduction

To achieve high colour fidelity for images across different computer platforms and imaging devices, progress has been made in colour imaging researches and the international standardisation of colour management by ICC (International Color Consortium).[4] Numerous colour management technologies have been proposed and examined in the past, whereby most studies developed for computer peripheral devices, e.g. monitor, printer, scanner.

First aim of this study is to extend applicability of colour imaging technologies, i.e. gamut mapping, image quality and psychophysical experiments, to enhancing image quality of television through adjusting mismatches between broadcasting signal, i.e. Rec. 709[8] and reproducible areas of display ASIC (A*pplication* S*pecific* I*ntegrated* C*ircuit*). Second aim is to develop a user-friendly interactive tool with four different functions for television engineers looking for using colour imaging technologies. This paper also describes a method by using the interactive tool above. Performance of method newly derived through the tool was evaluated by both psychophysical experiments and traditional QC (Quality Control) process. Television with ASIC designed by this study will come into market by LG Electronics Ltd., Korea.

Television Colorimetry

Broadcast television sources have attained a high fidelity of colour reproduction, especially those sources which convert an original scene to an electronic image.[3] These sources are mainly the electronic camera and film combination. The consistency and stability of these devices has improved over recent years by reason of adoption of the CCD and digital processing. Accurate colorimetry has been made possible by improved analytical and measuring techniques, some of which are fully automatic, and it is now possible to obtain a close match between like cameras and indeed between cameras from different origins. Electronic sources such as graphics and character generators do not convert the original scene but have clearly defined colorimetry during composition. The shortcomings of existing colorimetry are under investigation with the aim of producing a worldwide-improved standard. Four aspects are under consideration as follows: (1) an increase in the gamut of reproducible colours to encompass the full range of naturally occurring colours, (2) the correct application of luminance equation for colour encoding, (3) adoption of a single characteristic for non-linear correction, and (4) the adoption of constant luminance systems.

In this study, colour gamuts of PDP and standard broadcasting signal, Rec. 709, were investigated and compared. Figures 1 and 2 show 3-D and 2-D PDP and Rec. 709 gamut boundaries, respectively. Gamut boundary calculations for plot generation and data analysis depend on spherical gamut boundary descriptor.[2,3] These figures show that encoded colour information from input part cannot be reproduced fully into signal decoding part (receiver), particularly in blue and magenta areas. Other issues of PDP image reproduction are dynamic contour and tone irregularity in lower lightness level.

Interactive Tool Development

Although television-broadcasting standards have been specified by colorimetry, skilled experts have done display manufacturing quality control and display ASIC design. One of aims of this study is to provide an interactive development tool on the basis of colour imaging knowledge and technologies.

Interactive development tool (MagicQuality) developed is divided into four different components: (1) auto-measuring, (2) device characterisation, (3) image colour manipulation and (4) evaluation/analysis. Figure 3 shows overall menu design of MagicQuality.

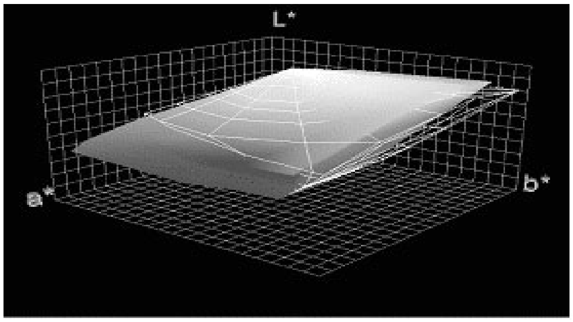


Figure 1. 3-D Representation of gamuts of PDP (solid) and broadcasting signal standard Rec. 709 (line)

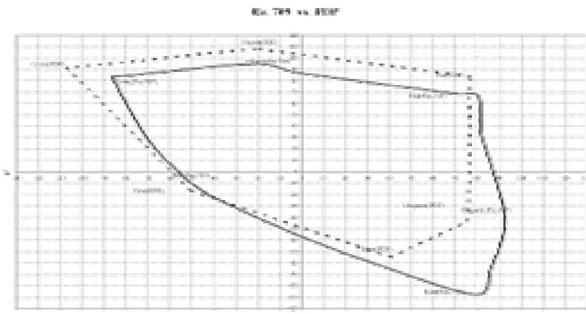


Figure 2. 2-D Representation of PDP (broken) and broadcasting signal standard (line) gamut extremes

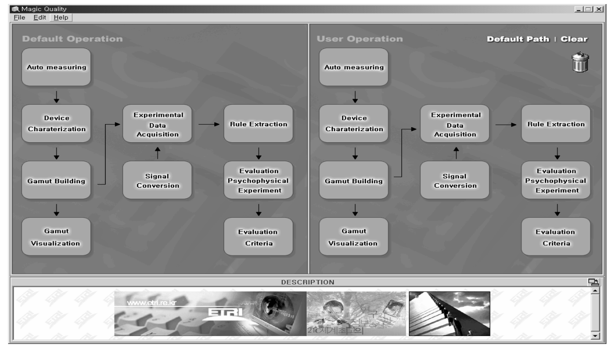


Figure 3. Overall design of interactive tool

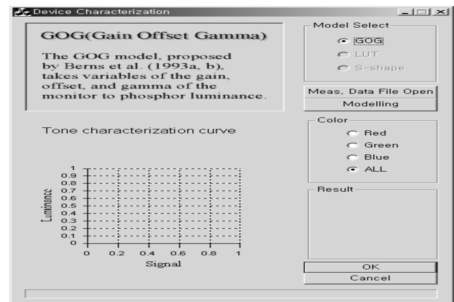


Figure 4. Device characterisation menu

Auto-measuring module was designed for developers to measure display colours automatically on the basis of IEC (International Electrotechnical Commission) standard, e.g. channel additivity, inter-channel dependency, and temporal stability. Data measured are transferred to device characterisation module (see Figure 4). In this module, coefficients of device characterisation equation, e.g. gamma, offset or look-up-table coefficients are derived automatically using data from measuring instrument.[1] This tool also gives opportunity to users to observe 3-dimensional gamut: shape, volume and size (see Figure 5).

Using the tool, display and television ASIC designers can modify the colour appearance of pictorial images in different regions of CIELAB colour space by adjusting their hardware configuration. The experiment was carried out for compensating colour mismatch between LG 54" PDP television and broadcasting signal Rec. 709. This module includes three components: (1) select a particular part of colour space, designated Colour Region Selection (CRS), (2) modify the colour appearance for the selected colour region via the L*, C* and hue angle controls, designated Colour Appearance Modification (CAM) and (3) enhance the image quality factors, histogram and sharpness modification, designated Image Quality Modification (IQM). Figure 6 graphically illustrates the menu structure.

Designing ASIC and display system, engineers and observers were asked to adjust the reproduction image to produce a close match to a real original object in viewing booth using the CRS, CAM and IQM functions. Observers first inspect which part of the reproduction image gave the most unsatisfactory match. He/she then selects the corresponding colours in CIELAB space via the CRS controls, and finally, adjusts the colour pixels in the image using the CAM controls. For example, an observer realises that the high key neutral colours in an image are too dark with a yellow tint. This module also gives opportunity for test image pleasantness experiment with one image on the screen.

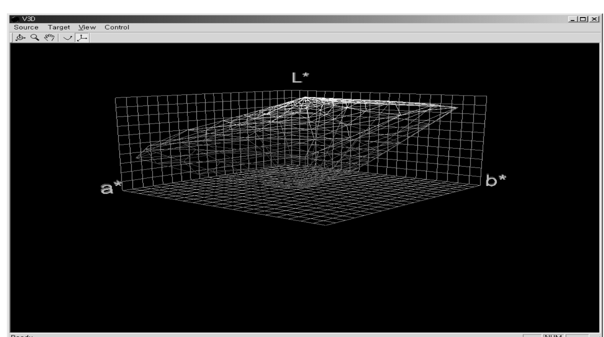


Figure 5. Gamut visualisation display menu

The CRS tool includes three controls: lightness, chroma and hue. For lightness and chroma controls, each was divided into three colour regions: high, medium and low ranges, i.e. L* of 0-35, 35-65 and 65-100, and C* of 0-25, 25-50 and 50 to the maximum achievable chroma respectively. For controlling hues, these were ranged between six different hue quadrants: red, yellow, green, cyan, blue, and magenta, i.e. 356.5-59.0, 59.0-128.0, 128.0-180.5, 180.5-226.0, 226.0-291.0, and 291.0-356.5 hue angle in degree respectively. The CAM controls allow subjects to modify colours by increasing or decreasing a particular colour with two units for lightness and chroma, and with one unit for hue. IQM module also gives opportunity to adjust image quality factors, i.e. histogram adjustment manipulation and sharpness. As most scenes of television services are not static, this tool also can adjust colours of moving image frames. Figure 7 shows this menu structure.

This interactive tool assist ASIC and display hardware designers to perform psychophysical experiments and analyse the experimental resulting data. Experimental analysis module calculates Thurstone's law of comparative data (Figure 8),[9] then analyse the statistical data using a spreadsheet, e.g. Microsoft Excel™, automatically.

Figure 6. Static image manipulation menu

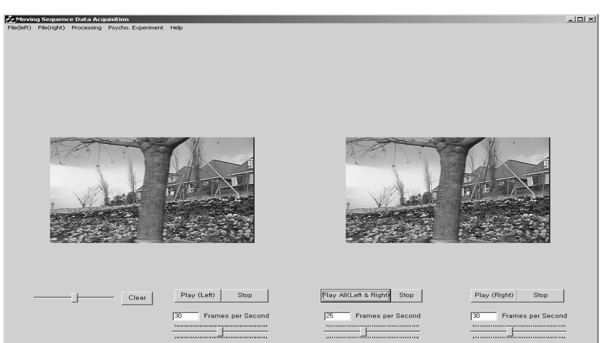


Figure 7. Moving image manipulation menu

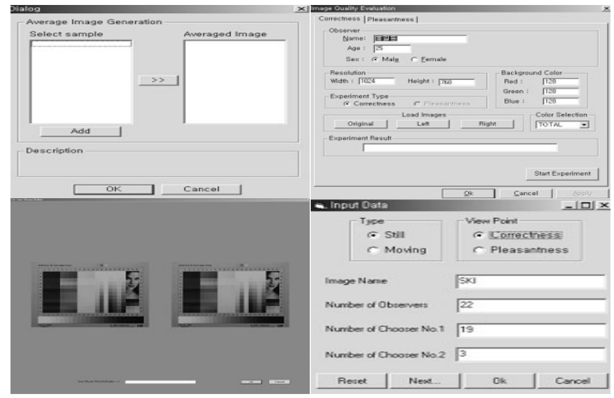


Figure 8. Psychophysical experimental data analysis menu

Experimental

Corrections by engineers were carried out by observing mismatches between original real objects and test images through broadcasting signal standard such as Rec. 709 or some leakage in calculation of colour difference components, i.e. constant luminance. Using the tool described above, reproductions through broadcasting signal were adjusted by ASIC designer adjusting colour and image quality factors using gamut visualisation, imaging manipulation interactively. In imaging manipulation module, base algorithm which provides first reproduction image given on the screen in order to modify mismatch between original in viewing booth and reproduction (PDP) is GUGMA (G*enerally* U*sable* G*amut* M*apping* A*lgorithm*) consisted of compression and extension.[5,6] Its procedures are described as below.

(Compression Part)

[STEP 1] Lightness Mapping

$$\text{if } L^*_{Min,o} \le L^*_o < (L^*_{Min,o} + ((16.9/A)\,(L^*_{Max,o} - L^*_{Min,o})))$$

then

$$L^*_r = \left[L^*_{Maxr} + \frac{1.8}{A}(L^*_{Maxr} - L^*_{Minr})\right] - \frac{10.65}{A}\left[(L^*_{Mino} - L^*_o) + \frac{16.9}{A}(L^*_{Maxo} - L^*_{Mino})\right]\left(\frac{L^*_{Maxr} - L^*_{Minr}}{L^*_{Maxo} - L^*_{Mino}}\right)$$

(Eq. 1)

$$\text{else if } (L^*_{Min,o} + (16.9/A)\,(L^*_{Max,o} - L^*_{Min,o})) \le L^*_o \le L^*_{Max,o}$$

then

$$L^*_r = L^*_{Max,r} - 1.18\,(L^*_{Max,o} - L^*_o)\left(\frac{L^*_{Max,r} - L^*_{Min,r}}{L^*_{Max,o} - L^*_{Min,o}}\right)$$

(Eq .2)

where *Max* and *Min* denote the maximum and minimum lightness values, subscripts *o* and *r* denote the original (Rec. 709 gamut) and reproduction (PDP display), and constant A is 100.

[STEP 2] Convergent Point Determination.

2-1: Lower Convergent Point

if $L^* < K_0$ then

$$\textit{lower convergent point} = 45\left(\frac{k_1}{100}\right)^2 - 2.8\left(\frac{k_1}{100}\right) + k_2 \quad \text{(Eq .3)}$$

otherwise

$$\textit{lower convergent point} = 45\left(\frac{x}{100}\right)^2 - 2.8\left(\frac{x}{100}\right) + k_2 \quad \text{(Eq. 4)}$$

2-2: Higher Convergent Point

if $L^* < K_0$ then

higher convergent point = K_1

otherwise

$$\textbf{\textit{higher}}\ \text{convergent point} = 45\left(\frac{x - K_0}{100}\right)^2 + K_1 \quad \text{(Eq. 5)}$$

where

- ***x*:** Lightness of a cusp of gamut (original medium, Rec.709). A colour to be compressed belongs to the same hue.
- **K_0**: The lowest lightness value of cusps of six primary and secondary gamuts (reproduction device)
- **K_1:** Mean of lightness values of cusps of six primary and secondary reproduction gamuts × 1.4
- **K_2:** Lowest lightness of reproduction device

[STEP 3] Simultaneous Lightness and Chroma Compression

The final step is to simultaneously compress lightness and chroma to find the reproduction colours using Eq. 6.

$$d_3 = 1.12\left(\frac{d_1 d_2}{d_0}\right) \quad \text{(Eq. 6)}$$

here

- **d_0**: Euclidean distance between convergent point and gamut boundary of original device
- **d_1**: Distance between convergent point and original colour
- **d_2**: Distance between convergent point and gamut boundary of reproduction device
- **d_3:** Distance between convergent point and compressed colour.

(Extension Part)

[STEP 1] A Linear Lightness Mapping

A linear lightness mapping is defined in the following equation.

$$L_r = 1.02L_o - 4.44 \quad \text{(Eq. 7)}$$

where subscripts *o* and *r* denote the original and reproduction.

[STEP 2] A Linear Chroma Mapping

$$C_r = \theta C_o \quad \text{(Eq. 8)}$$

where $\theta = 1.33$

Coefficient 'θ' was obtained using observer experimental data from previous study.[6]

Analysis

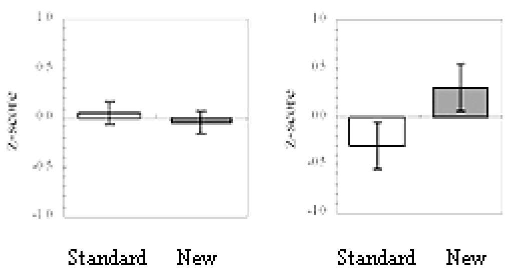
Using the tool, MagicQuality, three television engineers and six observers, who were staff of CSRL, ETRI took part in the first experiment, which was carried out in a darkened room. Two static and two moving objects were used in the first experiment. The 'IT8' image has commonly used as a reference target in imaging and reproduction industries and consists of colours with a wide range of chroma, lightness and hue together with skin tone. The 'flowers' object includes many highly chromatic colours of objects of which chroma is close to the extreme of reproducible boundary. Two moving objects have many chromatic colours and moved automatically in a viewing booth. Test images were captured using Sony DXC-H10 HD (High Definition) camera, then converted based upon standard broadcasting standard, Rec. 709. Observers were asked to modify complex images, which are finally processed through gamut compression and extension algorithms (Eqs. 1-8), on the PDP screen simultaneously comparing with real objects in the viewing booth. Resulting data from the first experiment were used to adjust coefficients of look-up-table in the post processing part of television display ASIC.

Second experiment was designed to evaluate performance of post-processing above. Three television experts and forty observers who did not participate in the first experiment joined in the second experiment. Four different static and two moving images, which were not used in the first experiment except IT8, were simultaneously shown to observers. Test images through broadcasting signal processing and modification from the first experiment were given to observers on LG Xcanvas PDP 40 inch DTV. In the correction experiment using the static test images observers selected closer one of two on the screen, one through digital video signal modification from the first experiment, or another just through standard signal processing, comparing with real objects on viewing booth in the darkened room. Pleasantness test was carried out just comparing two video clips on the screen: images through method derived by the first experiment or existing standard, Rec. 709.

Figure 9-11 show Z-scores using Thurstone's law of comparative.[9] In figure 9, it can be seen that newly-derived method generally outperform the existing television standard in moving image, though it can not be observed in the still test images. The results in terms of z-scores, methods by image and colour regions by method, are given in Figures 10 and 11. Figure 10 shows that newly derived method gives better reproduction in the images including skin-tone and low-chroma green colours. Figure 11 shows that new method compensates limitation of reproducible colours of standard broadcasting standard (see Figure 2). Using test images through standard and new procedures, traditional quality control experts also evaluated newly derived method outperformed in the lightness contrast, sharpness and colourfulness in blue and magenta colour areas.

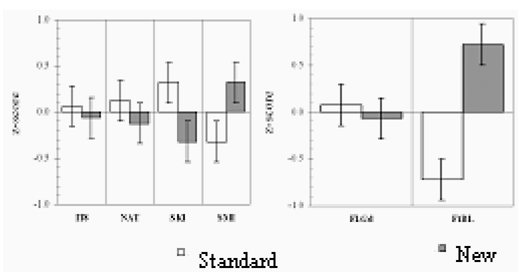
Conclusions

Numerous colour management technologies have been proposed and examined in the past, whereby most studies targeted computer peripheral devices.



(a) (b)

Figure 9.Overall z-score result of experiment ((a) still image, (b) moving image)



(a) (b)

Figure 10. Z-score result of experiment (image based, (a) still image, (b) moving image)

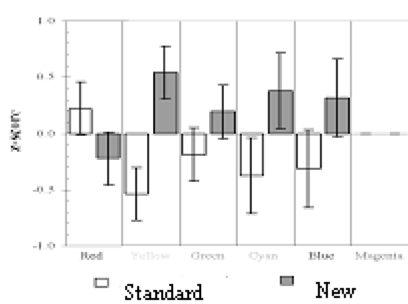


Figure 11. Z-score result of experiment (colour region based)

In this study colour management for broadcasting signal processing was investigated and development tool for this domain was introduced.

Firstly this study tried to extend research issues of colour imaging to enhancing image quality of plasma display panel television in terms of recovering mismatches between broadcasting signal, i.e. Rec. 709 and display ASIC. Secondly a user-friendly interactive tool was developed for television engineers. Performance of newly derived reproductions using the tool was evaluated by psychophysical traditional quality control procedures. Figure 12 shows test board configuration using ASIC developed in this study.

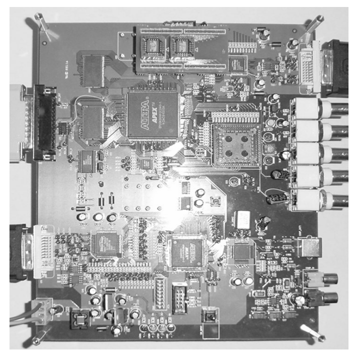


Figure 12. Board configuration using ASIC developed

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Biographies

Byoung-Ho Kang received his M.Sc. degree in computer science (AI) from the University of Georgia in 1993 and Ph.D. degree at the Colour & Imaging Institute, University of Derby in 2001, respectively. Since 1989, he has worked at the Electronics Telecommunications Research Institute (ETRI), Korea.

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