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Display and Storage Technology

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Overview

Author: *Kenjiro Kime**

Driven by digitalization of broadcasting, increasingly high-definition packaged media, and changes and diversification in video-display devices, all types of video/information equipment from home use to business use are undergoing dramatic changes. As a result, there is intense competition to improve the digital image quality and performance of display devices. Also, advances in networks and integration of broadcasting into communication technology are under way. Our imaging technologies, which are based on our laboratory's basic research integrated into commercial home-use equipment, have been developed for many years and are also found in business-use equipment. To improve digitalization and image quality, we have focused not only on simple image processing but also diverse fields such as differentiating our products in each display device category diversified and our storage devices. In Japan, the shift to digital terrestrial broadcasting will be completed in about 18 months. Although the process has been relatively smoothly so far, it is important to complete it by the target date. Therefore, a plan of comprehensive measures, led by the Ministry of Internal Affairs and Communications, was launched last year. Efforts such as setting up support centers, plans for collective housing, satellite safety net, and support for families on public assistance are being made nation-wide. Since the shift to digital terrestrial broadcasting will have a significant impact on various video-related equipment, successful completion is important.

**Living Environment & Digital Media Equipment Group*

Image Quality Improvement Technologies for Energy-Saving LCD TVs

Authors: *Yoshitomo Nakamura** and *Kohei Nomoto***

Introduction

We have developed an energy-saving, easy-to-view brightness control technology: the luminance of the liquid crystal display (LCD) TV screen is controlled to match the visual characteristics of the viewer. This technology has been adopted for the REAL MZW and REAL MXW series LCD TVs in the application of the Katei Gashitsu mode and energy-saving Katei Gashitsu mode.

1. Brightness Control under Household Conditions

In the 2006 REAL MX60 series LCD TVs, Mitsubishi Electric has introduced a brightness control function, “Katei Gashitsu mode”, which eliminates dazzle. This function is the result of research on actual viewing environments, studying the visual characteristics of viewers, and surveying the performance of display devices. The function automatically adjusts the luminance and hue based on the viewer’s age, viewing distance and characteristics of images displayed on the screen. Energy is also saved because the function controls brightness and reduces wasted energy.

1.1 Viewing environment

In 2004, we conducted a survey on lighting conditions in general households and found the average screen illuminance was 108 lx, while Nakata et al. in 1994 reported(1) a value of 93 lx, thus the screen illuminance in an average lighting environment is approximately 100 lx. The Katei Gashitsu mode was set based on a subjective evaluation under these lighting conditions.

1.2 Black image on LCD panel

Even if an LCD TV displays a black screen, the backlight is glowing, so a very black scene may appear gray due to light leaking from the backlight. Therefore, we evaluated the relationship between the screen illuminance and the required black level (Fig. 1), and using the results, control the brightness to match the black level in the Katei Gashitsu mode.

In a bright environment, surface-reflected light will degrade the reproducibility of black. Therefore, since the MZW series LCD TVs released in October 2007, we have applied an anti-glare coating to LCD panels, which suppresses surface reflection and internal diffuse light to enhance the reproducibility of black.

1.3 Dazzling luminance

On LCD TVs without brightness control, the maximum brightness is constant regardless of the displayed image. Therefore, an image with higher average brightness level will seem more dazzling than an image with a lower level.

We conducted an experiment to evaluate the dazzling luminance for both elderly (60 to 70s) and young persons (20s). The evaluation method used circular patterns of different display sizes to determine the luminance at which the subjects started to sense dazzling. The evaluation showed that dazzling was sensed at lower brightness when the area of the displayed pattern was larger, and under dimmer lighting dazzling was also sensed at lower brightness (Fig. 2).

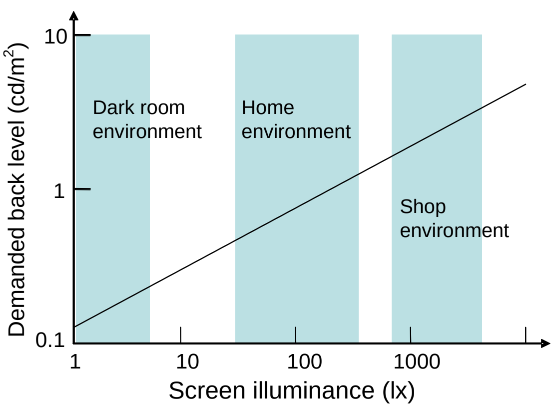

Fig. 1 Relation between screen illuminance and preferred black level

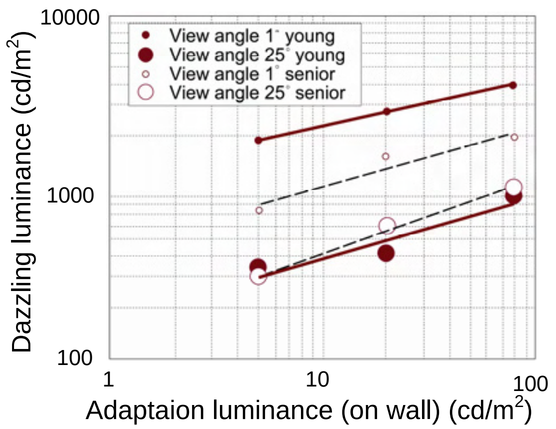

Fig. 2 Adaptation luminance and dazzling luminance

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1.4 Viewing angle and brightness

Figure 3 shows the relationship between the viewing distances at screen illuminances of 30, 100 and 300 lx, and the preferred luminance. The shorter the viewing distance, the larger the viewing angle and the lower the preferred luminance. The survey results(2) of viewing distances of adults and children revealed that children in their teens watched TV at a distance of 0.8 times that of adults. Therefore, since the MX60 series LCD TVs, the luminance is set for the viewing distance according to the setting of the illuminance sensor provided with 3-step intensity differences.

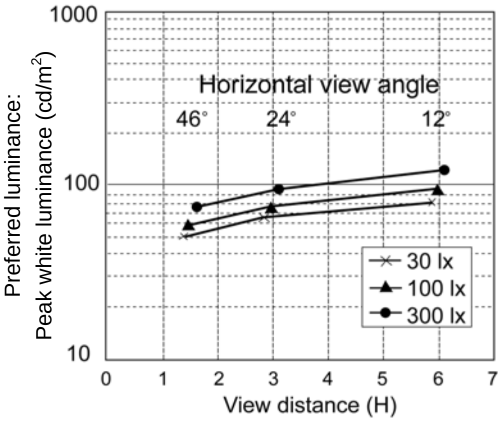

Fig. 3 Viewing distance and preferred luminance

1.5 Color temperature and feeling of brightness

The setting of color temperature of household TVs varies greatly, ranging from 7,000 to 20,000 K. The preferred color temperature of TV images depends on the age of the viewer and the preferred luminance. Figure 4 shows the relationship between the preferred luminance and color temperature of 20 elderly subjects. The figure shows that the higher the value, the stronger the preference. Elderly people generally tend to like images with higher color temperature because the spectral transmittance of crystalline lenses changes with age, but these results showed that subjects who liked higher luminance tended to like higher color temperature, and vice versa. The results are reflected in the Katei Gashitsu mode of the 2008 MXW200 series LCD TVs.

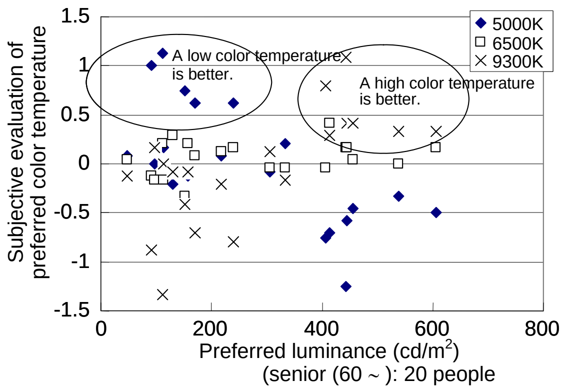

Fig. 4 Relation between preferred luminance and subjective evaluation of preferred color temperature

2. Brightness Control for Energy Saving and Image Quality

Figure 5 shows the relationship between brightness feeling and display luminance. The Katei Gashitsu mode controls luminance in the “bright” area where dazzling is not felt. The energy-saving Katei Gashitsu mode installed in the 2008 MZW200 series LCD TVs evaluates the brightness when viewers do not feel that a household environment is dark, and controls luminance in this area.

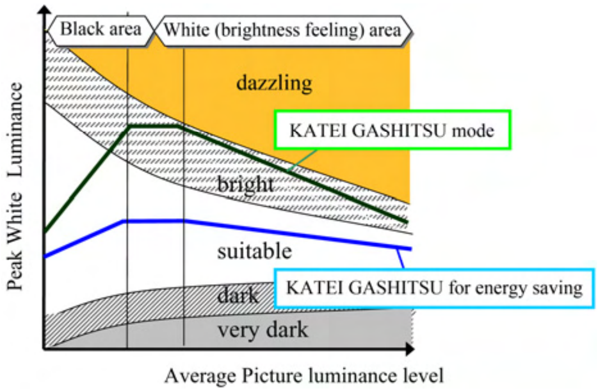

Fig. 5 Peak white luminance and brightness feeling

2.1 Permissible lower bound and preferred luminance evaluation

To evaluate the appropriate luminance area, a reference value is determined using the following two evaluation indices:

(1) Preferred luminance: Brightness at which viewers do not feel eye fatigue, even when viewing for a long time, and can continue to watch the high-quality images

(2) Permissible lower luminance: Brightness that is permissible when energy saving is taken into consideration

The evaluation was performed using a 46-inch type LCD TV in a household environment, and with 20 subjects aged 20 or older. Figure 6 shows the results: The preferred luminance was between 50 cd/m^2 and 500 cd/m^2, and the permissible lower luminance was between 20 cd/m^2 and 250 cd/m^2.

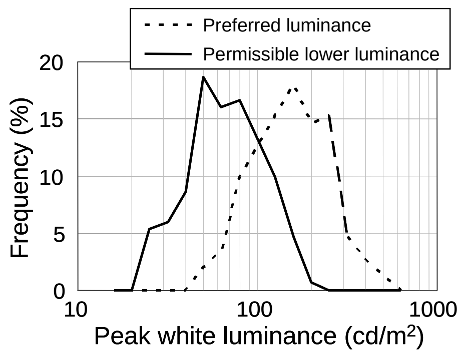

Fig. 6 Distribution of preferred luminance and permissible lower luminance

Considering these results, we chose a luminance that 90% or more of the subjects did not think was dark, and a display luminance that 50% or more of subjects preferred, for the setting values. With these settings, the annual electricity consumption of the MZW200 series LCD TVs was 168 kWh/year for the 40-inch type and 185 kWh/year for the 46-inch type, among the most energy-efficient in the industry.

2.2 Settings for image quality and energy saving

Viewers generally prefer higher luminance, so the key when choosing an appropriate luminance setting is to maintain high quality image at an appropriate display luminance. This luminance level for high quality images was obtained from experimental data and theoretical analysis.

2.3 Ordered Stimuli Multi-dimensional Image Quality Optimization (OSMIQO)

People's preference for image quality is based on fixed regularity, which is common to many of them[3]. Therefore, to achieve an image with an appropriate luminance area, the regularity of image quality was obtained by a subjective evaluation. People other than TV engineers were selected as subjects, and the Ordered Stimuli Multi-dimensional Image Quality Optimization (OSMIQO) method was developed and used, in which subjects watched multiple images of different quality and evaluated them. The following two approaches were selected in this method in order to compare many combinations of image quality parameters within a small number of evaluations:

(1) Two or more images were compared in an evaluation.
(2) To simplify the evaluation, only one parameter of image quality varied among the shown images; the other image quality parameters remained fixed. The images to be compared were lined up in order of the varying parameter's value and presented to the subjects.

2.4 Experimental method

For this experiment, black level, gamma and color temperature were selected as the image quality parameters to be adjusted. Figure 7 shows the correspondence between the experimental scene and image quality parameter space. The images used for the experiment included sports, news, a variety show, and a movie.

The subjects selected their most preferred image quality of those presented, and then were asked to rank the remaining inferior image qualities according to five grades, comparing them with the most preferred one.

2.5 Theory of analysis

We should compute the entire potential distribution of preference in the image quality parameter space, based on the experimental data that covers the relation between some of the image qualities.

A new algorithm was needed to compute this potential distribution, since experimental data was limited. To construct this algorithm, the following three points must be considered:

(1) The optimum image quality may not be just one—there may be two or more optimal points within the space.
(2) Generally, there are multiple paths from an arbitrary point to the optimal point within the space.
(3) A contradiction may occur in human evaluation, and there is a possibility of returning to the original image quality when better quality is tracked.

Consequently, the OSMIQO method was developed as this algorithm.

2.6 Analysis results

Figure 8 shows the potential distribution of preference during a variety show program—the three subfigures show the evaluation function of the preference vs. color temperature and gamma when the black level is fixed. As can be seen from these subfigures, the lower black level setting was preferred. The same result holds true for other contents, which revealed that people truly demand deep black, even during a low-luminance setting.

In addition, the gamma and color temperature affect each other, showing a strongly non-linear potential distribution when the black level is low. These results are the tacit rules for the preference of image quality.

Based on these results, the image quality of the MZW200 series LCD TVs was specified. Thus, the series achieves industry-leading energy saving while offering an image quality that a majority of people prefer.

3. Conclusion

The luminance level must be set to an appropriate brightness to reduce the power consumption of LCD TVs. However, people must still like the image quality, so we will use the energy-saving Katei Gashitsu and OSMIQO developed in this study to improve image

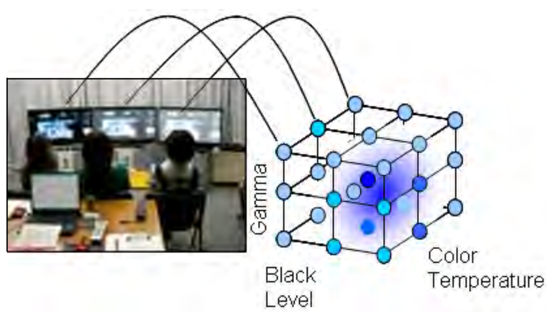

Fig. 7 Experimental scenes and image quality parameter spaces

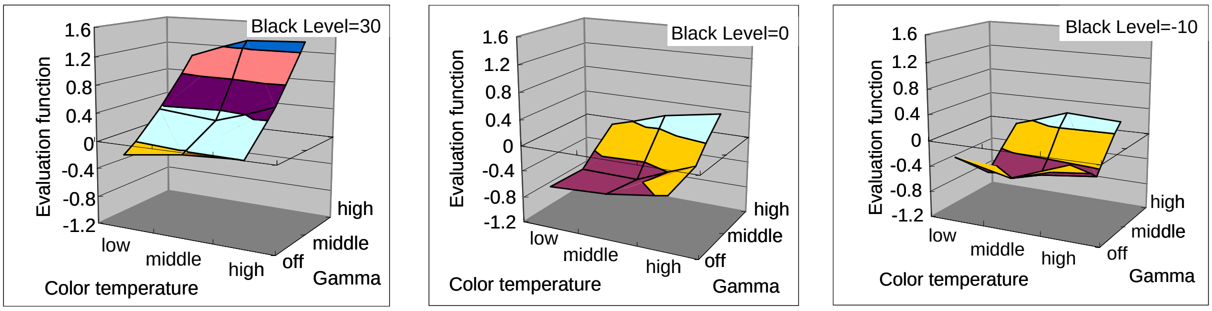

Fig. 8 Correspondence of evaluation image and image quality parameter space (case of variety show program)

quality and save energy, all at the same time, in various ways in the future.

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New Optical Disc Technologies for Blu-ray Discs

Authors: *Nobuo Takeshita**, *Kazuhiko Nakane** and *Tomo Kishigami**

Introduction

Mitsubishi Electric has developed a system that automatically optimizes the write strategy for optical discs in order to shorten the development period of Blu-ray Disc (BD) recorders and to ensure stable performance. We have also developed tools for verifying logical specifications, which verifies the disc logical information recorded by a BD recorder or created by a BD content authoring system.

1. Technology for Automatic Optimization of Optical Disc Write Strategy

1.1 Write strategy for optical discs

A BD recorder performs laser light modulation, which is called the write strategy, thereby precisely creating recording marks according to the recording data length, in order to correctly record data on a BD disc. The write strategy involves disc-specific optimal adjustments for optical discs. A typical optical disc recorder pre-stores many types of optimal write strategies in its memory for use when recording. Since the optimal write strategy differs depending on the optical specifications of the optical pick-up and the discs, optimal write strategies for all discs must be prepared when the optical pick-up is modified due to a change in model of the optical disc recorder.

Figure 1 illustrates a write strategy for BDs. The BD uses recording data with 2T to 9T (where T indicates the channel clock period), and creates marks according to each recording data, which requires the laser emitting pattern to be controlled for the multi-pulse type.

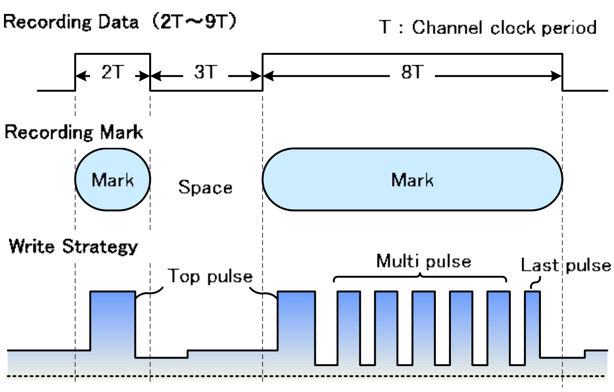

Fig. 1 Write strategy for BD

1.2 System for automatic optimization of write strategy

We have developed a system that automatically optimizes the write strategy, which depends on the characteristics of an optical disc, using a DVD recorder. Figure 2 is a block diagram of the system. The write strategy is optimized by analyzing the playback signals obtained by test recording with a DVD recorder using a digital oscilloscope and computer, and by repeating the closed loops in which the correction amount in the write strategy is fed back to the DVD recorder. The optimization for analyzing playback signals and adjusting the write strategy amount was efficiently achieved by the operators' optimization skills and expertise.

Specifically, the optimization process starts with the step in which the initial write strategy is set in a DVD recorder, and then 8/16-modulated random data are recorded on a DVD disc. Next, the recorded data is played back, and the playback signals after equalization (EQ) that are output from the DVD recorder are stored in a digital oscilloscope. After this process, the playback waveform data after A/D conversion are stored in a computer. The playback waveform data are processed at the playback signal analysis and write strategy calculation blocks. The playback signal analysis block extracts jitter and several waveform parameters from stored playback waveform data; then, based on these parameters, the write strategy calculation block determines the next write strategy setup values. These

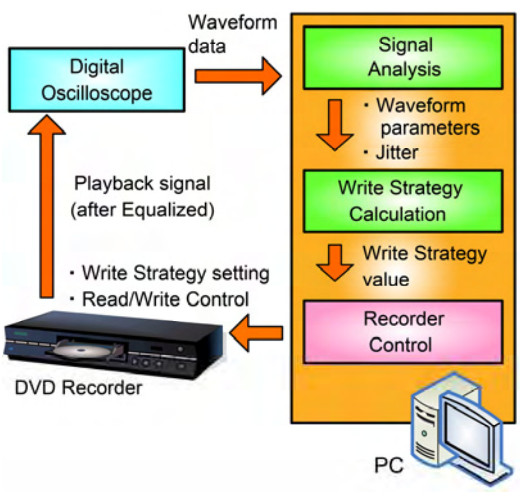

Fig. 2 Block diagram of automatic write strategy optimization system

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processes are repeated until the jitter and waveform parameters satisfy the target values, and finally the optimal write strategy is determined.

Figure 3 shows the processes in the playback signal analysis and write strategy calculation blocks. The playback signal analysis block calculates the signal widths (mark and space widths) based on the slice level from the playback signal data. For mark and space widths, average values are calculated from each recording data length. The peak level corresponding to the recording data with 3T is extracted from the playback signal. The write strategy calculation block selects the parameters of the write strategy required for correction based on the waveform parameters obtained at the playback signal analysis block, and calculates the corrected values. When the jitter and waveform parameters satisfy the target values, the automatic optimization system outputs the optimal write strategy.

1.3 Evaluation of characteristics

In order to examine the performance of the newly developed automatic write strategy optimization system, the jitter performance and optimization time were evaluated using 16 types of commercially available DVD-R discs produced by different manufacturers. Figure 4 shows the jitter performance obtained by the automatic optimization system. As this figure indicates, all discs showed acceptable jitter values, which were lower than the target value of 8%. Figure 5 illustrates playback signals before and after the optimization: (a) shows the playback signal when recording is made using the initial write strategy; (b) shows the playback signal recorded using the optimized write strategy. Lack of sharpness is shown in (a), which indicates the variation at the portions where waveforms are overlapped. Such variation is caused by the influences of inter-symbol interference and waveform distortion because the write strategy is not optimized. On the other hand, in (b), the variation is remarkably eliminated at the portions where waveforms are overlapped. The time required to automatically optimize the write strategy in this system is shown in Fig. 6. As can be seen, the optimization takes from 45 seconds to 2 minutes, 30 seconds. In addition, an automatic write strategy optimization system for BDs is developed by replacing the recorder block of the system with an evaluation equipment that can perform recording on and playback of BD recorders to customize the optimal algorithms for BD's.

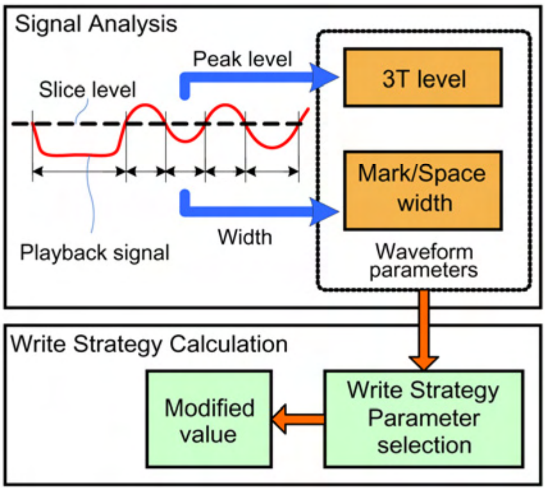

Fig. 3 Signal analysis and write strategy calculation

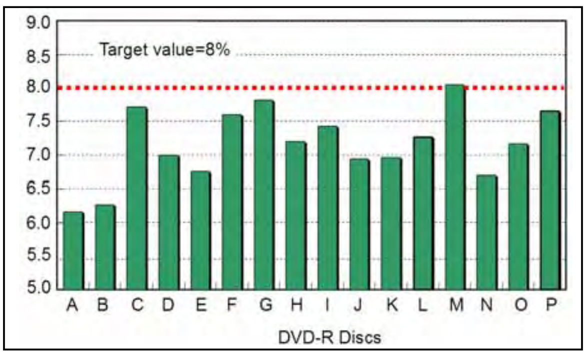

Fig. 4 Jitter value with optimized write strategy

2. Structure of BD Specifications and Formal Verification Tools

2.1 BD specifications

Figure 7 shows the structure of BD specifications. The specifications are classified into three layers. The specifications for the physical layer consist of specifications for rewritable discs, recordable discs, and read-only discs. These three specifications define the type of optical disc and the characteristics of its re-

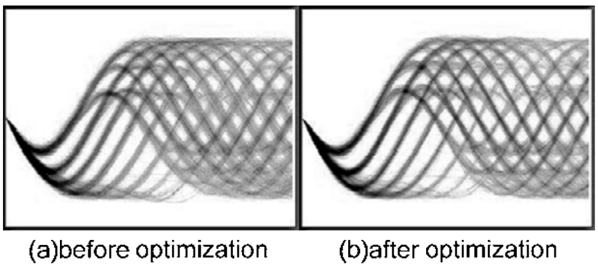

Fig. 5 Playback signal of before and after optimization write strategy

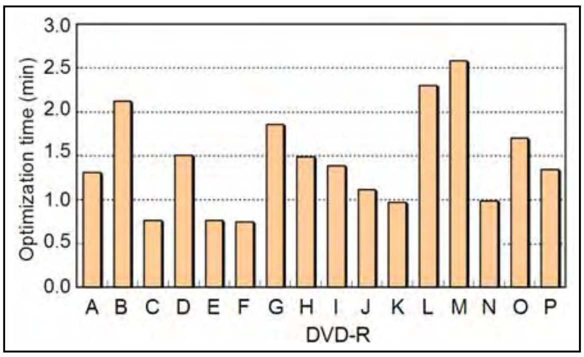

Fig. 6 Time for write strategy optimization

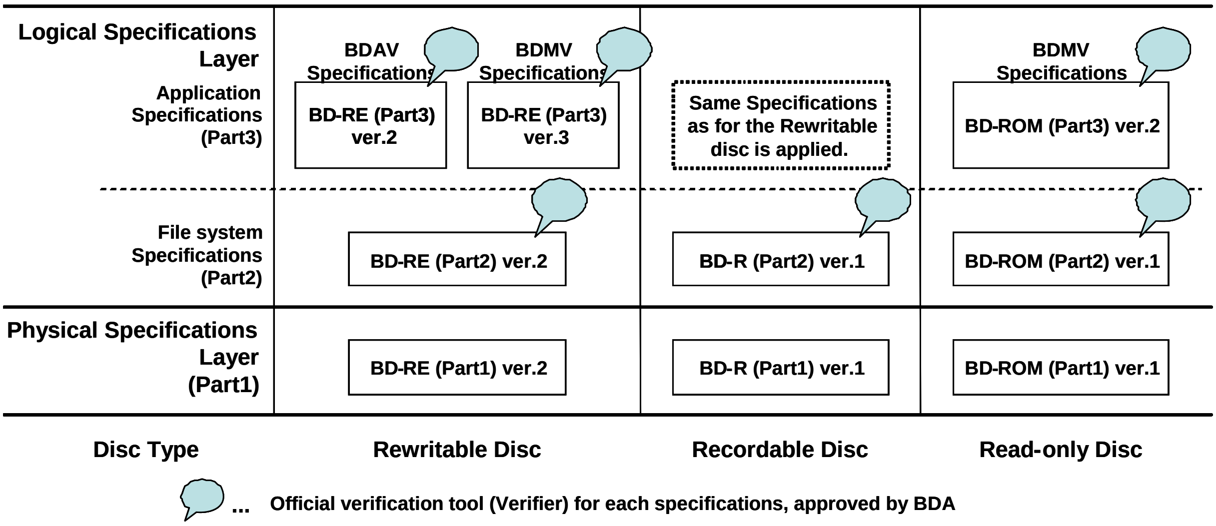

Fig. 7 BD specifications and formal verification tools

cording and playback signals. To maintain and improve the recording signal quality of optical discs, which are interchangeable media, the disc characteristics must conform to those of the recorder. To ensure compatibility between various types of commercially available discs and recorders, it is necessary to secure the quality levels between them. The specifications licenser, BDA, dictates verification tests to the manufacturers to assure compatibility, and only those products that pass the test are certified as BD products. This verification test includes two kinds of tests. One is a confirmation of the signal quality of a disc when it is recorded by a reference recording device; the other is a confirmation of the recording signal quality of a recorder when it records data on a test disc having the qualified characteristics.

The file system and application layers are collectively referred to as logical layers, which define the alignment and meaning of all data on the optical disc, which include video content to be recorded as digital data files or file management data for them. For the recorder that records video content, the digital video data format recorded on a disc must conform to the logical specifications. In the verification test, test data is recorded on a disc and the disc is analyzed with the formal verification tool, called a verifier, to check whether the data format and alignment satisfy all definitions and conditions in the specifications. There are three specifications for the file system layer, corresponding to each physical specification. The application layer also has three specifications: the Blu-ray Disc Audio/Visual specifications (BDAV) for broadcast program recording, the Blu-ray Disc Movie specifications (BDMV) for movie content, which realizes various video presentations, and the specifications for using the BDMV specifications for personal recording. Verifiers were prepared for each specification.

Compatibility of BD discs recorded by one BD recorder among the other BD recorders or players is assured by confirming that all products satisfy conditions of the specifications in the formal verification test.

2.2 Formal verification tool

Figure 8 shows the configuration of the BDAV specifications verifier used for the recorder verification test, as an example of the formal verification tool. Digitized video data are classified into the stream data group that represents video and audio for a certain period of time, and the control database group that manages and controls the stream data including the connecting relations and replay conditions of each stream data. Each of them is recorded on the disc as a separate file. The specifications define the detailed format of these data, and thus, the recorder shall create data files so that all conditions are satisfied upon recording on a disc.

The verifier, which is a software program that runs on a personal computer, reads recorded data on a disc through a BD drive installed in the personal computer to conduct a test. The verifier is used to inspect whether or not the contents of each file above defined in the specifications conform to the specifications and to precisely inspect whether or not the contents in the management database are consistent with the contents of the stream data groups and their allocation on the disc. If nonconformance to the specifications or inconsistency among data is found, information about the conformance error to the specifications is reported.

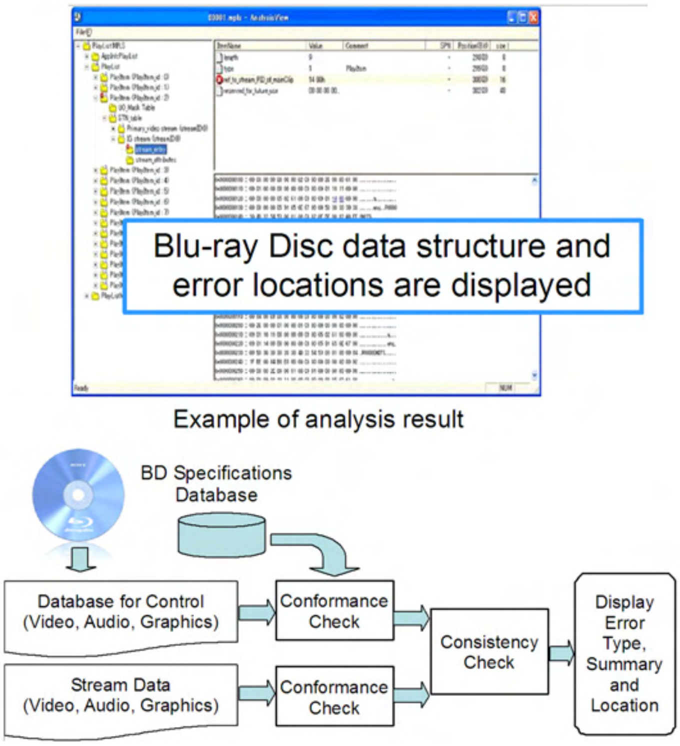

Fig. 8 Functions and features of verifier

The BDAV specifications employ both Moving Picture Experts Group (MPEG)-2 and MPEG-4 Advanced Video Coding (AVC) High Profile. The verifier supports these video compression technologies. The stream data are analyzed in a unit of Group of Pictures (GOP), and conformance to the relevant parameter of the video compression technology standard, which are referred to in the BD specifications, is also inspected. The developed verifier reduces the verification test time by using multi-thread processing for verification operations, and features viewer functions that interactively display management database syntaxes and stream data structures. These features make it easier to detect recorder design failures.

3. Conclusion

We have developed a system that automatically optimizes the write strategy for recorders and drives. We have also developed formal tools for verifying logical specifications for the verification test that checks whether BD products conform to the BD specifications, which are used by BD testing centers.

UI Software Development for Digital Recorders with the UI Design Tool "NINA"

Authors: *Nobutoshi Todoroki** and *Yoshihiro Yamaguchi***

Introduction

The cost of developing user interface (UI) software has continued to rise as embedded devices become more functional and UI designs become richer. We have been developing the UI design tool "NINA (Navigator for Interface of Application)" to improve the efficiency of UI development for such embedded devices and reduce the cost. This report discusses the application of NINA to the UI development of a digital recorder and its successor models, and evaluates its effectiveness.

1. UI Design Tool "NINA"

"NINA" is a UI design tool for embedded devices; it consists of several functional modules used on PC and a software module for target device (Fig. 1). Although embedded devices have numerous functions and setting items, the screen size is often limited. Therefore, the UI for embedded devices is generally operated by switching the screens for each particular procedure. "NINA" is used to design the UI based on the concept of SCO (State Chart Object), which is useful for modeling UI involving such switching of screens.

1.1 SCO

SCO is a UI component that consists of more than one state and transitions between states. Each state has one scene layout. The scene layout that corresponds to the SCO state at a certain point is displayed as the external appearance of the SCO at that point.

In each scene layout, other SCOs can be laid out as UI components in addition to the basic UI components, such as buttons and labels. This enables the SCOs to be made hierarchical, which allows the designer to design all custom UI components on screen to the UI of device application in the same framework, and then operate them by combining them.

Figure 2 shows an example of the hierarchal use of SCOs. SCO1 has two states – stop and play of music – and when a button is pressed, the device transfers to the other state. In the scene layouts of each state, the UI screens that correspond to "stop" and "play" are created. SCO2 achieves the UI that displays the playback screen when a track to be played is selected. On the playback screen, SCO1 is laid out in the scene layout as a custom UI component. Modifying the design of SCO1 in such designing also automatically changes the playback screen of SCO2.

1.2 Components

An overview of the major components of NINA is given in Fig. 1. The chart editor is a tool for designing the transitions between the UI screens as state diagrams. It also describes the procedures in response to key events during device operation and other events generated in the device, as an event handler. The event handler is written using a Java-based simple script language (Java is a registered trademark of Sun Microsystems, Inc.).

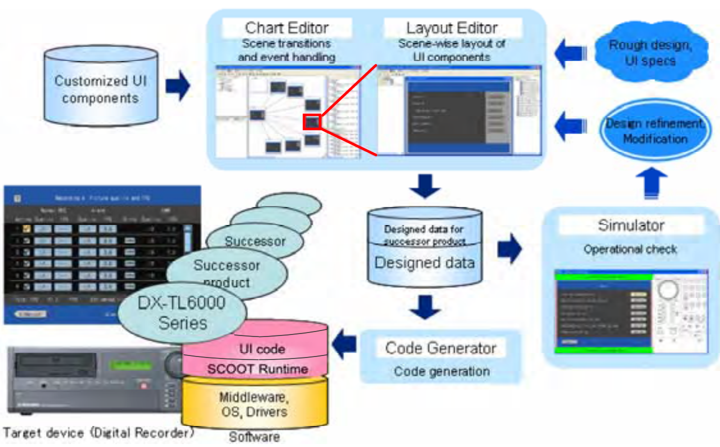

Fig. 1 The structure of NINA and the UI development flow

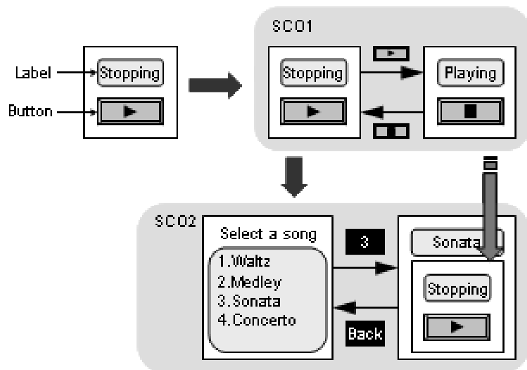

Fig. 2 Hierarchical use of SCOs

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The layout editor creates a scene layout in each state of the SCO. A scene layout combines the SCOs and the basic UI components, including labels, buttons, images, and containers that group the UI components.

The simulator is a tool which simulates the UI operation designed using the chart editor and layout editor, allowing the designer to check it on a PC used for development.

The code generator uses the UI design data to generate C++ source code for target devices: The generated codes do not include any platform-dependent process and do not need to be modified by the programmer.

The SCOOT (SCO Oriented Technology) runtime is a software module written in C++. It runs the source codes generated by the code generator on a target device.

2. UI Development of Digital Recorder

We used NINA for the UI development of our DX-TL6000 digital recorder for Japan. Based on the UI, we have developed UIs for six successor models such as DX-TL308E, including models for Europe. An overview of the digital recorder and the UI development of these models using NINA is given below.

2.1 Overview of digital recorder

The digital recorder is a business-use surveillance device which is mainly embedded in the security surveillance system of retail stores and banks. It digitally records surveillance images for a long time.

The latest DX-TL6000 models use a USB mouse and have a simple menu so the user can operate the recorder like a PC. The features of this UI are as follows:

(1) The user can operate the UI using both the front buttons on the front panel and the USB mouse. The front buttons include the six operation buttons: up, down, left, right, enter and back. These buttons move the focus that indicates the UI component that the user is currently manipulating or scroll it, thus selecting the item on the screen and operating "enter/back" to move between the screens or set values. The user can also use the USB mouse to move the cursor and click it just like using a PC.

(2) A digital recorder has particular operations – Focus management in the vertical and horizontal directions, defined in a complicated manner, and nested focus management. The following focus management is performed on the screen shown in Fig. 3:

- Pressing the enter key when a block-shaped UI component is being focused will move the focus to the UI component within the block. In the block, the focus will move by operating the left and right keys.
- Pressing the enter key when a UI component in a block is being focused will move the focus to the entire block.
- Clicking the mouse on each UI component will directly move the focus to the component.

2.2 UI development by using NINA

To achieve the UI described above, the following UI components have been developed:

(1) Extending basic UI components

The basic UI components have been extended so that they can be operated by both pressing the front buttons and clicking the mouse.

(2) Designing custom UI components for digital recorders

Complicated focus management can also be achieved by describing it using script language. How-

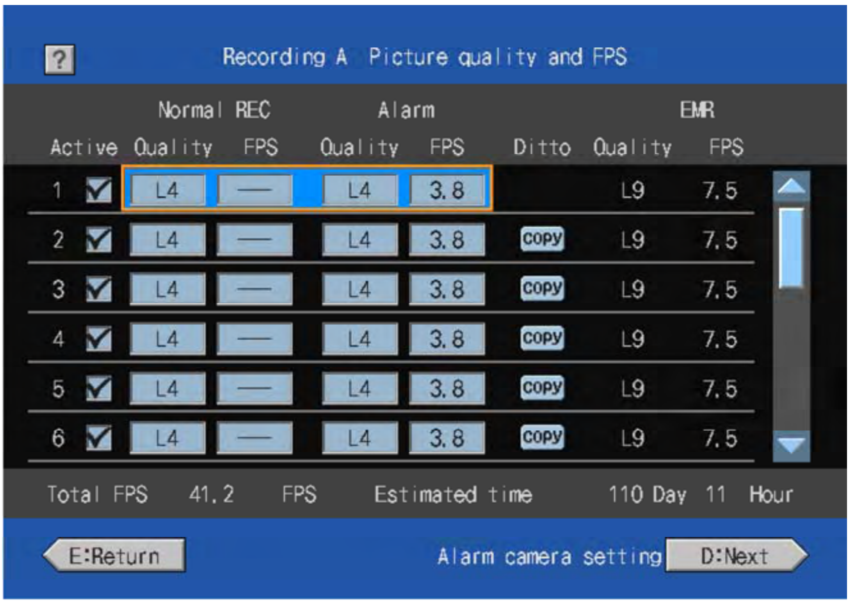

Fig. 3 A setting menu

ever, there are many similar screens, so many clones of code are generated, which increases the quantity of coding and makes it difficult to cover all changes when the specifications are to be changed. To prevent this, we offer custom UI components that include each focus management as the UI design using the framework of SCO. This component can be laid out in the same way as a basic UI component on various screens. Even when the focus management specifications are changed, simply revising this UI component will be reflected in all screens that are using the UI component.

The UI was developed by developing this UI component. As a result, a 580-screen UI was developed in 16 man-months.

2.3 Developing UIs of successor models using NINA

The UI development of six DX-TL6000 successor models is outlined below. The major changes in UI specifications from the DX-TL6000 are as follows:

(1) There are fewer cameras to be controlled and fewer options for various settings.

(2) The video signal used in the models for Europe is different: the screen display area (in the vertical direction) is 1.2 times that in models for Japan.

For (1), the scene layout for fewer options was also added to the UI component that displays the setting items, and each layout is selectively displayed corresponding to the model. For (2), we provided a new basic UI component for which two types of layout parameter can be set and the layout can then be switched for display. Simply replacing the previous basic UI component with this new one allows the display to handle two types of layout using the one screen.

Based on these change strategies, the UI of six successor models was developed. This encouraged reuse of the UI design, and the development was completed by partially revising and adding the definition of UI design, taking only 2.6 man-months.

2.4 Evaluation of application of NINA

With the DX-TL6000, the types of screen increased considerably compared with previous models, and the specifications became much more complicated because the mouse and operation buttons were used concurrently. Nevertheless, the UI was achieved using only half the man-hours of the previous UI. This section describes the evaluation of this achievement, and also considers reusing the UI design in developing future successor models.

2.4.1 Reducing the number of created screens by common use

One common screen that can be used as a base is created, and UI components are then added or deleted as necessary. This allows the designer to express many screens, and this common use of screens substantially reduces the number of created screens in the UI specifications with many similar screens. We analyzed the UI specifications prior to development and tried common use of screens (Table 1). The number of actually created screens was 253, so we successfully reduced the number of screens to 44% of that defined in the UI specifications.

Table 1 UI development cost of DX-TL6000

	Development man-hours	No. of specified screens	No. of created screens
Development scale	16 man-month	580	253

2.4.2 Increasing development efficiency by introducing custom UI components

With the screen in Fig. 3, we compared the man-hours required to describe all focus movement/scroll movement using a script language, and when using a custom UI component. In the latter case, the man-hours for the focus portion were reduced by 65% and the man-hours for designing the UI were reduced by 39% for the entire screen in Fig. 3. Therefore, the man-hours required for the product as a whole will be further decreased.

2.4.3 Increasing the efficiency of development by using a simulator

If a detailed test is conducted in a prior work process using the simulator function of NINA, faults in the post-work process can be reduced. Table 2 shows the number of faults in the UI portion in the simulator test and system test: it is clear that, among the faults that can be detected in the whole work process, 90% were detected in the prior work process.

Table 2 Simulation test and system test results

	No. of test items	No. of detections
Simulator test	6100	487
System test	20000	53

2.4.4 Increasing the efficiency of development of successor models

When developing six successor models, we modified the UI design of the DX-TL6000, using it as the base. Table 3 shows the number of SCOs that could be reused in the development of these models. SCOs accounting for 63% of the entire design could be reused for designing the DX-TL6000; the development man-hours for the remaining 37% were 2.6 man-months.

Table 3 Number of reused SCOs and newly developed SCOs

	Total No.	No. of reuse	No. of new/additional creation
No. of SCO	270	170	100

3. Conclusion

The UI design tool NINA was used to develop the UI of digital recorders. Since the framework of reusing the UI design was used, the UI development efficiency was improved when developing an initial product and successor models. We will continue to develop successor models in the future.

Laser TV

Authors: *Kuniko Kojima** and *Akihisa Miyata***

Introduction

Mitsubishi Electric has developed the world's first large-screen laser television system using a three primary color laser light source. This television features super-high resolution with double the color reproduction gamut and high contrast ratio compared to conventional LCD televisions. Displaying vivid and dynamic images, this large-screen television features a compact design, and will open up new horizons.

1. Background of Laser Television Development

We have commercialized the world's first laser television system using a three primary color laser light source. This television features double the color reproduction gamut and high contrast ratio compared to conventional LCD televisions. Through this laser television system, we propose a new type of large-screen television with super-high resolution and innovative compact design.

The demand for large-screen televisions has been growing as high-vision broadcasting featuring high-definition images becomes increasingly popular. Moreover, since viewers tend to prefer to watch a large-screen television, the demand for large-screen, high-quality-image televisions with high definition and wide color reproduction gamut has been growing. Meanwhile, work on the worldwide standardization of extended color space, the color space that can render a wide color gamut, has been under way(1)(2). The extended color space xvYCC, which is the standard for motion pictures, was internationally standardized in January 2006. Display devices have also been supporting wide-gamut color reproduction(3).

2. Features of Laser Televisions

Our laser television realizes an extremely wide color reproduction gamut which is double that of traditional LCD televisions by employing a three primary color laser light source. This wide color reproduction gamut produces vivid images which could not be displayed in the past.

The laser television incorporates a newly developed laser light source, super wide-angle optical engine dedicated to the laser with far smaller optical system thanks to its smaller diameter by taking advantage of the laser light with small divergence angle, thin screen, small case, and compact laser driving power supply. Thanks to the design with these compact components, the laser can be hung against a wall. Moreover, since the laser light source with high luminous efficiency is optimally driven with the lighting control circuit, the power consumption is as low as 135 W, one-third that of a conventional LCD television, even though the screen size is large.

This television includes 3D video display function, enabling both normal broadcasting and 3D images to be shown on one laser television. By wearing dedicated glasses, multiple viewers can enjoy dynamic 3D images with high color reproduction on the wide screen at the same time.

3. Development of Laser Television

We started developing laser televisions in earnest in 2005. After prototyping 52-inch and 56-inch televisions, we then developed and marketed 65-inch laser televisions(4) to (6). Table 1 lists the specifications of laser televisions that have been developed.

The 52-inch prototype television developed in 2006 was used to study color reproduction gamut of the laser light source and color rendering methods as a basic verification of the optics of laser light image rendering. The 56-inch prototype television developed in 2007 was used for verification of thinner product designs. Since both prototypes were intended as fundamental prototypes, the optical engine was installed in the television case, but the laser light source, laser light source driving circuit, and video signal processing circuit were stored in the table on which the television rests. The laser light source and optical engine were connected through optical fiber cables.

The laser television developed and marketed this time contains all components within the case with a depth of 269 mm. For compactness, the laser light

Table 1 Specifications of laser TV

	208 LaserVue	2007 Prototype	2006 Prototype
Screen size (inches)	65	56	52
Laser power (cd/m^2)	500	500	500
Lawser power (W)	19.4	19.6	18
Dimensions (HxWxD) (mm)	1011x1466x269	918x1280x263	864x1260x473
Color gamut on u'v' (%) (vs ITU-RBT_709)	208%	182%	179%

*Advanced Technology R&D Center **Kyoto Works

source, laser driving power supply, and optical engine were made smaller. Moreover, a new laser module was developed to deliver a luminance of 500 cd/ m^2 (@ 12,000 K) with a 65-inch television. Also, an advanced video signal processing LSI is used in this laser television. These element technologies are explained below.

4. Element Technologies of Laser Television

As shown in Table 1, an ultra-thin laser television with screen size of 65 inches and depth of 269 mm was developed. A small optical engine with increased light utilization efficiency was also developed, which produces a luminance of 500 cd/m^2 (@ 12,000 K) with a 65-inch television. Figure 2 illustrates the color reproduction gamut of the laser television represented on a u' v' chromaticity diagram. This laser television has double the color reproduction gamut compared to conventional LCD televisions.

Figure 3 shows the new optical engine for laser televisions. This engine incorporates a super wide-angle projection optical system that consists of a projection lens and aspherical mirror, which can project as large as a 65-inch screen from the aspherical mirror at a projector distance of 100 mm. A large convex aspherical mirror, which is included in this engine, minimizes color aberration and distortion, which are typical problems in super wide-angle projection. The diameter of the optical system has been made smaller thanks to the higher directionality of laser light than lamp light, hence the optical system is smaller and the contrast is higher. Figure 4 (a) shows the newly-developed projection lens for the laser light source and Fig. 4 (b) shows the conventional one for a lamp light source [7]. Since the diameter of the optical system is smaller, the maximum effective diameter of the projection lens is reduced by about 40%. This super-wide angle projection system realizes an optical engine dedicated to thin laser televisions with increased image quality and compactness.

Figure 5 illustrates the laser light source unit developed for our laser television. To design a thin laser television, the laser module for RGB, cooler for the laser module, laser driving power supply, and control circuit are included in the unit which is just 106 mm thick. The control circuit for the laser light source receives the light-up timing signal of laser from the video signal processing circuit, and drives the laser based on this signal. Each of the laser modules includes a laser and coupling optical component, and thus the laser light from the laser is input into the optical fibers through the coupling optical system. The laser light source unit and the optical engine are connected by the optical fibers, which guide the laser light illuminated at the laser light source unit to the optical engine.

The wavelengths of the three RGB primary colors used in the development are 447 nm for blue, 532 nm

Fig. 1 Laser TV

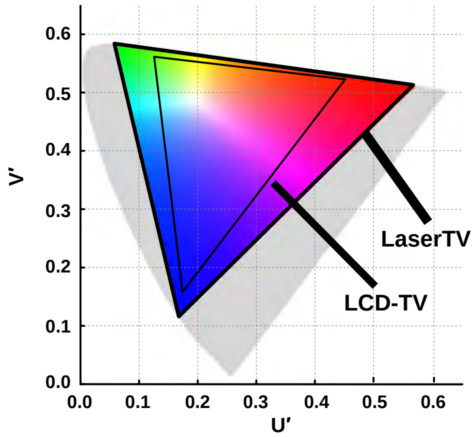

Fig. 2 Color reproduction gamut

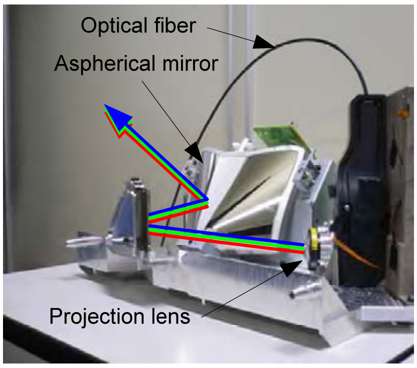

Fig. 3 Compact optical engine

Fig. 4 Projection lens

for green, and 640 nm for red. The peak outputs are 6.3 W for red, 5.0 W for green, and 8.1 W for blue, totaling 19.4 W. This ratio is designed to give the optimal color temperature of white. Modules including the coupling optical component connected to the optical fibers that link the laser light source unit and optical engine are also downsized.

Figure 6 shows the new laser light source for green. A 5.0 W optical output of green light is successfully obtained in this single device.

If conventional video signals are rendered on a display with wide color reproduction gamut, an unnatural image with darker colors is displayed due to the large difference between the color space in video signals and that of the display. Conventional video signals are designed based on the color space for cathode ray tubes(8). In a display with wide color gamut, which typically has an LED or laser as its light source, the difference between the color space of video signals and that of the display becomes significant. If conventional raw video signals are rendered, deep colors are vividly rendered, and light colors are also rendered darker, because the narrow color space of video signals is linearly enlarged on the large color space of the display. If a memory color such as that of flesh is rendered reddish, the flesh color will look unnatural to viewers.

We have solved this problem using Natural Color Matrix (NCM), our proprietary color management technique. The NCM technique allows video signals to be resolved into a luminance component and 12 color components, and then re-composed into video signals that are suitable for the color space created by laser television, through matrix operations.

Figure 7 shows the chromaticity measurements of typical colors displayed on a laser television and a liquid crystal television. The colors were sampled from several scenes in the contents for assessment. As shown in the figure, colors that are close to the original color are reproduced with greater depth on the laser television due to its large color reproduction gamut, while the flesh color plotted in the center is reproduced with almost the same chromaticity. This shows that the non-linear color mapping of NCM allows colors that are close to the original color to be reproduced more vividly, which are unique to laser television, than on conventional televisions, while light colors such as flesh color are reproduced similarly to those on conventional televisions. This means that more visually powerful images with natural and deep colors will be displayed using the conventional video signals. If necessary, NCM can reduce the color reproduction gamut of laser television to the gamut of conventional television. In addition, the newly developed signal processing system conforms to

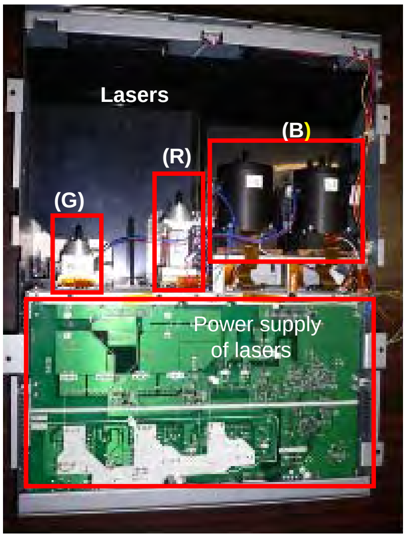

Fig. 5 Laser light source unit

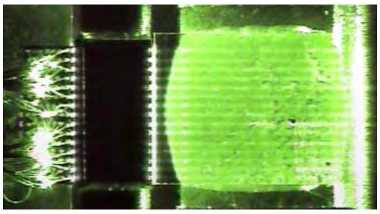

Fig. 6 New green laser

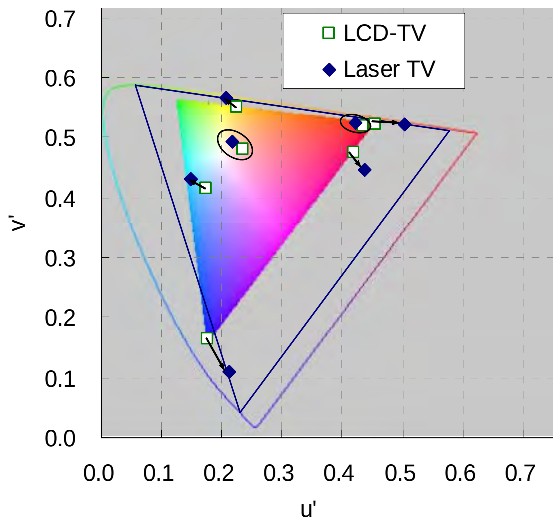

Fig. 7 Color reproduction of laser TV

x.v.Color (See Note 1), which allows high-fidelity color reproduction in large color space.

5. Summary

We have commercialized the world's first laser television system using three primary color laser sources. By developing a new driving power supply, signal processing technology, optical engines, screens,

Note 1 A trademark that shows compliance with xvYCC (IEC 61966-2-4), an international standard for extended color space used for moving video pictures, which was approved and issued by the International Electrotechnical Commission (IEC).

and cases suitable for the new laser sources, we have paved the way for large-screen televisions with 3D video display function, while achieving a compact size and low power consumption.

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