A DIGITAL VIDEO CAMERA SYSTEM

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ABSTRACT

This is to report on a new video camera control system developed for extending the dynamic range of present single-chip CCD camera of which dynamic range is inherently limited.

This is accomplished by controlling the dynamic range by utilizing a signal which discriminates the contrast of object, by compensating the white balance by detecting achromatic parts of object out of video signals, and by reducing pseudo-color effects produced at a region where high-frequency components are abundant. This reports further on new LSIs and other functions developed for realizing this system.

I. INTRODUCTION

Whereas consumer-use video cameras have to be single-chip CCD types from the imposed size, weight and cost limitations, their dynamic range are inevitably narrow because of the limited capability of CCD and the inadequate system control capabilities.

There are some basic problems such as inadequate saturation characteristics and glooming also. Fundamental solutions of these problems involve the improvement of CCD itself, but this requires long-term advancements of LSI device and process technology.

In order to improve the present situation, however, the authors developed a method for extending its dynamic range by acquiring contrast informations of objects from CCD image signals and by controlling the camera system accordingly.

Together with this new dynamic control method, this paper reports further on a new method to compensate white-balance more accurately by means of signals discriminating the achromatic part of object from the CCD image signals. This paper further reports on a method for reducing psuedo-colors that could take place in regions where high-frequency components are abundant. This phenomenon is inherent to single CCD video cameras. Also reported here is an outline of LSIs developed to implement the presently developed digital camera system.

2. FUNDAMENTAL CONCEPT

Consumer-use video cameras respond to changes in luminance and contrast of an object by controlling only their iris and AGC gains. This control is adequate to maintain the signal level at constant when the change of luminance is in a range from 10 to several hundred thousand lux, and is also adequate for taking a low-contrast object such as gray scale image under a front-lighted condition.

However, if a portion of object is placed in an excessive frontlighted and high-contrast condition, the bright area may be staurated or dark area may be masked, or both effects may take place even if the contrast increase were only 6 dB, and this would result in poor image reproduction on a monitoring screen.

Although narrow dynamic range is inevitable characteristics of single-chip CCD video cameras, a substantial improvement of image reproduction character-istics is possible by changing the camera characteristics according to the contrast of object.

In order to accomplish this, a video camera system having capabilities to detect the contrast of object and to control the camera characteristics beside the gain characteristics is developed. These two capabilities are essential to control the dynamic range and system characteristics in response to the changes of contrast levels.

A method for detecting the contrast of object from the image signal level distributions is described in Chapter 3. Upon contrast detection, either one of three control processes described below are executed.

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(1) When the contrast of object is low, the dynamic range of detected image signals is narrow so that only the iris control is performed as in a case of conventional video camera system.

(2) When the contrast is slightly higher than the case of (1) and the deficiency of dynamic range is within 6 dB, the iris is closed, and the average signal level drop caused by this is compensated by increasing the system gain. At the same time, the signal level is compressed below the standard level by controlling the knee circuit in order to prepare for the peak level increases.

(3) When the contrast is still higher and the deficiency of dynamic range is more than 6 dB, the iris is opened to make the image luminance higher so that the signal would not be masked under the dark level.

The narrow dynamic range of single-chip CCD video camera can be brought at the near center of contrast by employing the above described control processes. This prevents excessive iris closing and saturation of highlight portions, and the substantial expansion of apparent dynamic range, and thus a camera having a nearly idealistic performance can be accomplished.

3. CONTRAST DETECTION AND SYSTEM CHARACTERISTICS CONTROL

3.1 Detection of Object Contrast

In order to make the application of contrast information to video camera control possible, stable contrast informations have to be acquired from the CCD image signals independent of the iris conditions. The implementation of these function within a smallest scale circuit is another task to be done.

In order to accomplish the first task, the authors developed a method to determine the contrast by dividing CCD image signals into a sufficiently large number of blocks for signal level evaluations. Then, by setting an average level locating at 25% below the peak level as a reference level, the iris is so controlled to maintain this reference level constant.

Under this iris control condition, five typical images including two low-contrast images under frontlighting shown in Photographs 1 and 2, two high-contrast images under backlighting shown in Photographs 3 and 4, and one relatively high-contrast image having an excessively front lighted part at around the center shown in Photograph 5 are prepared, and the control situations for these are considered.

The signal levels of these blocks are arranged in a descending order at an decrement of 4% and are averaged. Fig. 1 shows five distribution patterns of signal levels taken for these five images. The level-order numbering along the horizontal axis shows a signal level distribution arranged in a descending order.

Fig. 1 shows that the backlighted images can be discriminated at Level-orders 1 and 2, and the frontlighted and excessively frontlighted images can be discriminated at Level-orders 11 to 16. By combining these two conditions together, discriminations between the backlighted, frontlighted, and excessively frontlighted images are possible.

In order to accomplish the latter task, the number of divided blocks was decreased from 1,600 to 400, 100, and 25, and the changes in signal level distributions were analyzed. Figs. 2 and 3 show the respective signal level distributions which are different from those shown in Fig. 1, and show the cases of 100 and 25 blocks. The backlighted and high-contrast images can not be accurately distinguished in these cases because of the decreased values at Level-orders 1 and 2 which correspond to peak levels of these two images. Therefore, an employment of another small scale detection circuit is permissible for the peak level detection.

As for Level-orders 13 to 17, there are distinctive differences in the signal level distribution between front-lighted and excessively frontlighted conditions so that the contrast of objects can be determined without difficulties. From now, the values at Level-orders 13 to 17 are referred to as median values.

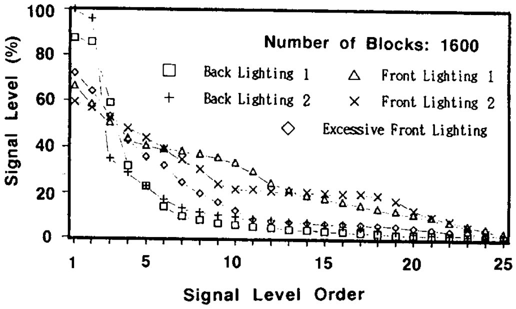


Fig. 1 Distribution of Block Signal Levels

Photo 1 Front-lit image 1

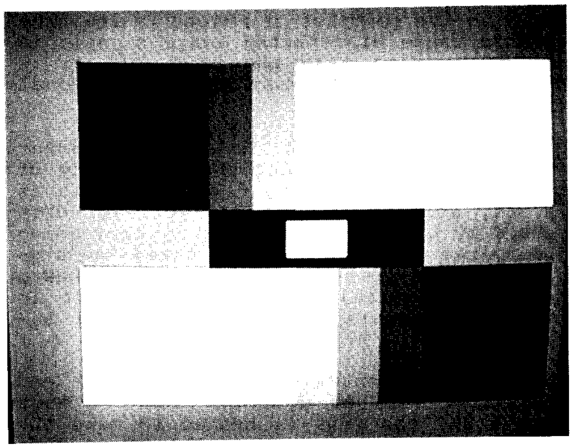


Photo 2 Front-lit image 2

Photo 3 Back-lit image 1

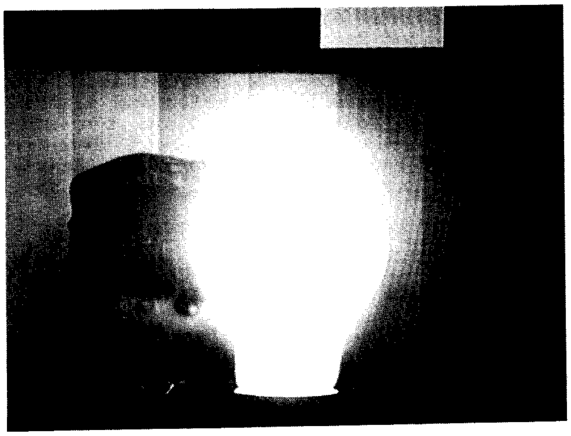


Photo 4 Back-lit image 2

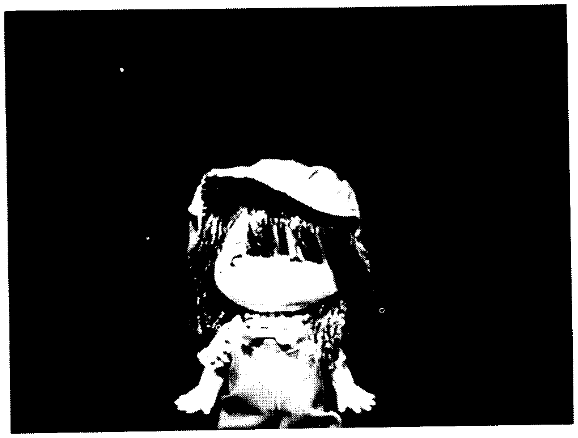


Photo 5 Excessive front-lit image

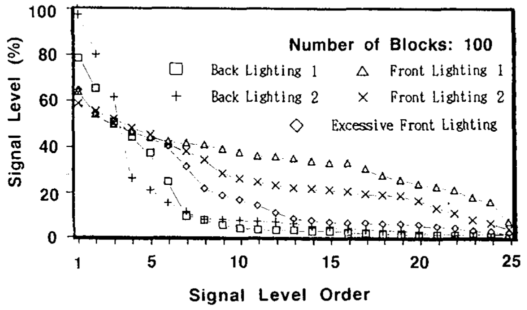


Fig. 2 Distribution of Block Signal Levels

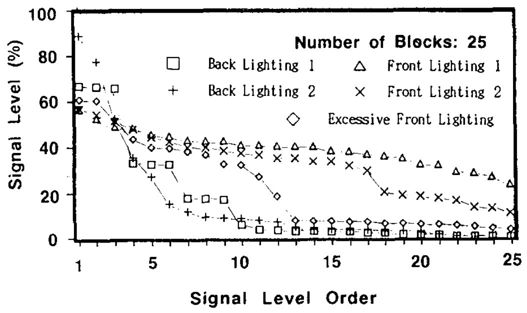


Fig. 3 Distribution of Block Signal Levels

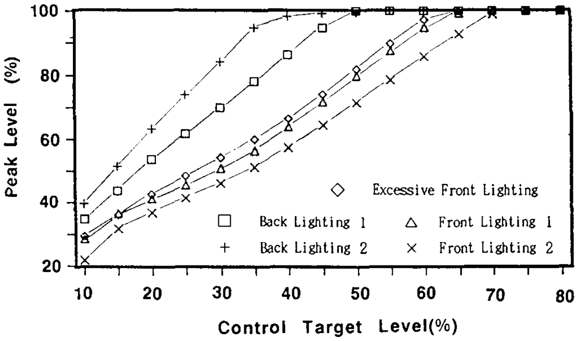


Fig. 4 Peak Values of the Test Images

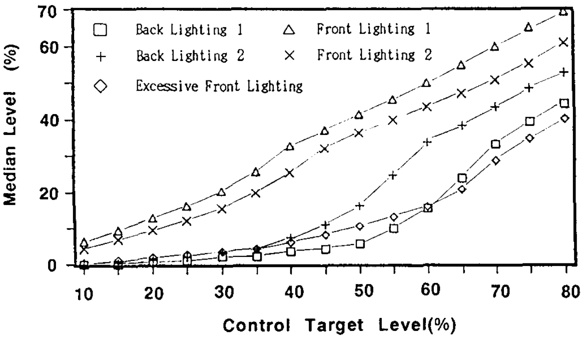


Fig. 5 Median Values of the Test Images

In addition to the above, distributions of both peak and median values are examined when the control target level of the reference value set for the iris control is varied centering around 50%. In order to reduce the circuit scale, the number of block division is determined to as 25 in the present case.

Fig. 4 shows changes of peak values of the five typical images by varying the control target level of reference value from 10% to 80% in a step of 5%.

The above shows that backlighted high-contrast images can be distinguished within a range of 15% to 55% of the control target level of reference value. Fig. 6 shows a region wherein this discrimination is effective. This region can be divided into two regions of high-level (H) and the median and low levels (M, L).

Fig. 5 shows changes in the median values of five images of different dynamic ranges when the control target level of the reference value is varied from 10% to 80% in a step of 5%.

These indicate that the low-contrast images taken under a frontlighted condition or the relatively high-contrast images taken under an excessive frontlighted condition can be distinguished in an entire range of reference level.

Fig. 7 shows a region where this discrimination is possible, and this region is divided into two regions of the high and median levels (H, M) and the low level (L). Table 1 shows a method to discriminate the dynamic ranges from the respective region distributions shown in Figs. 6 and 7.

By analyzing the distribution of block signal levels as above, the discrimination of image contrasts in a range from 15% to 55% of targeted reference level becomes possible.

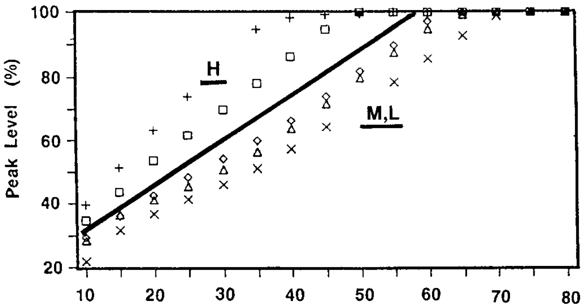


Fig. 6 Region of Peak Values

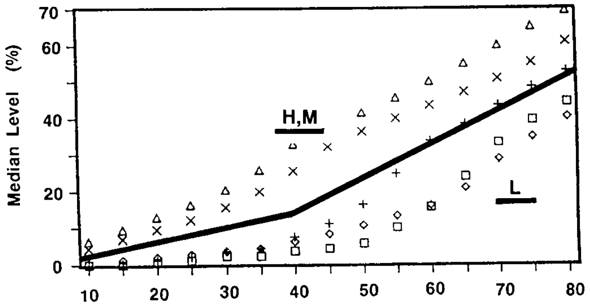


Fig. 7 Region of Median Values

Table1 Classification of different contrast condition

Condition	Contrast	Peak	Median
Back lighting	High	H	-
Front lighting	Low	M,L	H,M
Excessive front lighting	Middle	M,L	L

H: High Level M: Middle Level L: Low Level

3.2 System Characteristics Control

As shown in Sec. 3.1, a total camera system control for achieving an ideal image reproduction becomes possible by determining the contrast level of object. The camera system elements controlled by contrast level informations include the lens iris, circuit gain, knee-point and the highlight aperture. Table 2 shows controls required at various contrast conditions i.e., frontlighting, backlighting, and excessive frontlighting.

For a low contrast image taken under a frontlighting condition, only the iris control is necessary as done in a conventional camera system. For an image having a slightly higher (+6 dB) contrast taken under an excessive frontlighting, the iris has to be slightly closed for preventing CCD saturations. In this case, the peak level is set at a control target level, and a maximum attainable reduction is approx. -6 dB.

A drop of average signal level, if took place, is compensated by increasing the system gain for a maximum of +6 dB. If the signal peak level is increased at the same time, the knee-point circuit is controlled to compress the signal level to or below the reference level.

To the highlight signals compressed by the knee-point circuit, highlight aperture signals are synthesized to improve the image definition. For the higher con-

Table2 System controls for different contrast condition

Condition	Iris	Gain	Knee&HL-ap
Back lighting	Open	Up	ON
Front lighting	Normal	Normal	OFF
Excessive front lighting	Close	Up	ON

trast images taken under a backlighted condition, the iris is opened to introduce brighter images toward CCD. This is carried out because the compensation by closing the iris and by increasing the circuit system gain reduces the S/N ratio of image excessively and these are considered impractical.

The above described algorithm enables the shifting of narrow dynamic range of single-chip CCD video camera to a near center of the contrast of object placed under a backlighted condition. Since this sets the control at the highlighted area of object under an excessively high frontlighted condition, this extends the dynamic range by 6 dB maximum.

Thus, this feature prevents both excessive iris closing and saturation of localized highlighted area, and enabling a video camera to take full advantages of single-chip CCD video camera performance.

Photographs 6 to 8 show the results of video cameras controls performed by the informations obtained from above described contrast detection processes. Photograph 6 shows a case where only the iris control is performed i.e., no dynamic range control is made, and Photograph 7 shows a case where a dynamic range control based on the contrast detection is performed. Photograph 8 shows a case where iris is gradually opened without dynamic range control to bring the darker gray scale area to a level that could be attained by dynamic range control. In this case, the brighter gray scale area is saturated because the limited dynamic range of camera.

A comparison between these three photographs proves that the saturation of bright image can be substantially reduced and the glooming of gray scale area can be improved by applying the presently developed dynamic range control.

4. COLOR TEMPERATURE DETECTION

Knowledges of color temperature of lighting or lighting equipment illuminating a white object are essential for executing an authentic white balance. The presently employed automatic white balance control is performed by clipping color difference signals for averaging, and by controlling the gain of color difference processor to bring the averaged value to zero.

This bases on a concept that the averaging of image signals over an entire frame averages the hue of object, and makes the image nearly achromatic also. However, a drawback of this method is that discoloring may take place if a chromatic object is taken. This problem is particularly pronounced when the object has a light color, and it is impossible to reproduce the original colors in such a case.

For solving this problem, the authors devised a new white-balance control method referring to a white object recognized by video cameras in advance. A table of color difference signal levels is prepared by taking an achromatic color chart under varying color-temperature illuminations.

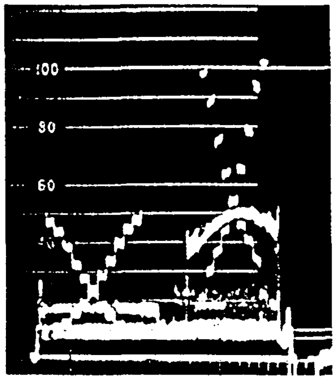


photo 6 A case without dynamic range control

Photo 7 A case with dynamic range control

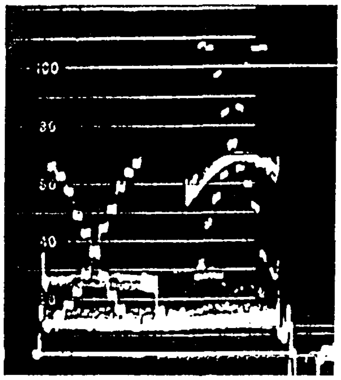


Photo 8 A case iris was opened without dynamic range control

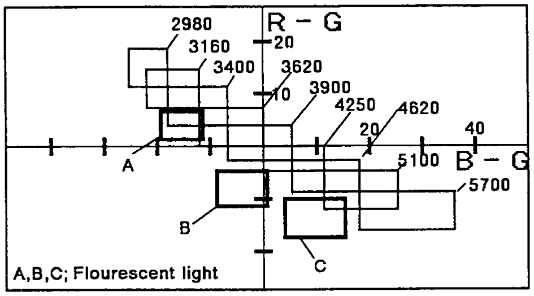


Fig. 8 Range of achromatic colors of various color temperatures

1) Averaging color difference signal over an entire frame using blocked signal.
*1st averaging signal

2) Search achromatic table for color difference signal level which is nearest to 1st averaging signal.
*1st color temperature

3) Check number of blocks in 1st color temperature.
\>>> IF less than 5: go to 1)
\>>> IF more than 5: go to 4)

4) Averaging color difference signal in 1st color temperature.
*2nd averaging signal

5) Search achromatic table for color difference signal level which is nearest to 2nd averaging signal.
*2nd color temperature

6) Check number of blocks in 2nd color temperature.
\>>> IF less than 5: go to 1)
\>>> IF more than 5: go to 7)

7) Averaging color difference signal in 2nd color temperature.
(Renew 2nd averaging signal)

8) Control white balance using 2nd averaging signal and go to 5)

Fig. 9 White balance control algorithm

Then, an acquired picture is divided into 25 blocks, and a search is made to detect if there is any block of which characteristics are close to one of those data stored in the table, and the white-balance control is executed by referring those data.

Fig. 8 shows a range of achromatic colors of various color temperatures employed to detect white colored objects, and Fig. 9 shows a detailed white-balance control algorithm.

By endowing the system achromatic color data at various color temperatures, discriminations between the color difference signals produced by lighting and the color difference signals produced by a chromatic object becomes possible, and the exact determination of color-temperatures becomes possible also. Therefore, this contributes to solve the most of discoloring problem due to the presently employed white balance control process.

An exceptional case where the discrimination between chromatic and achromatic colors can not be made is a case where a chromatic color of object is close to the spectrum of lighting source.

5. SYSTEM CONFIGURATION AND LSIs

5.1 System configuration

Fig. 10 shows a schematic system configuration developed for video cameras. The sample hold, AGC, and γ-correction sections are constituted of analog circuits for relieving the circuit from excessive A/D conversion loads. The 2H delay circuit is shared between the separation process of color difference sequential signal from CCD and the vertical aperture compensation processing.

The vertical and horizontal aperture compensations are adaptively performed by controlling the AGC gain and YL signal level. When AGC gain is high and YL signal level is low, the aperture compensation is lowered for reducing noises and picture degradation. Fig. 11 shows a relationship between aperture compensation and YL levels taking the AGC gain as a parameter beside NF shown by a broken line. The value of NF is derived by the following equations.

$$NF = 10\ \mathrm{Log}\ ((G^2{}_2 + (1+G)^2/2)$$
$$YL(Z) = Z^{-1} + Z^{-2}$$
$$AP(Z) = G(-1 + Z^{-1} + Z^{-2} - Z^{-3})$$

wherein YL(Z) and AP(Z) represent filter characteristics by which YL and aperture compensation signals are synthesized, and G is a factor indicating the aperture compensation signal gain.

The reasons for NF taking a negative value when the aperture compensation is zero is that YL is synthesized from signals of two pixels. The color signal gain is controlled by detecting edges of image for reducing psuedo-colors generated at locations where an abrupt luminance signal change takes place. This phenomenon is characteristic of single CCD video camera.

Because a detected edge could be chromatic, the suppression of color difference signal gain is limited to 12 dB at maximum. The horizontal aperture compensation signal synthesizing filter is utilized for the edge detection, and its characteristics are shown in Fig. 12.

The color difference sequential signals derived from CCD are separated and synchronized by using three lines of signals. The white-balance control is so performed that each pixel signal gains a to d could satisfy the following conditions:

$$a\ (Ye + Mg) - b\ (Cy + G) = 0$$
$$c\ (Mg + Cy) - d\ (Ye + G) = 0$$

The pixel signals used here are block-by-block signals derived by algorithm in Fig. 9 based on the achromatic color tables prepared for various color temperatures.

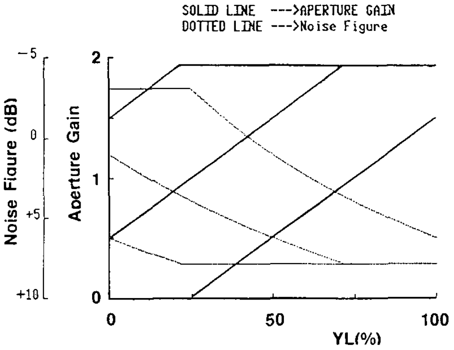


Fig. 11 Relationship betwee aperture gain and Noise Figure

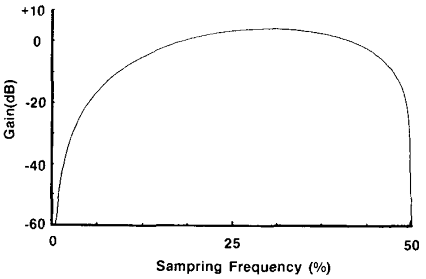


Fig. 12 Frequency response of edge detection filter

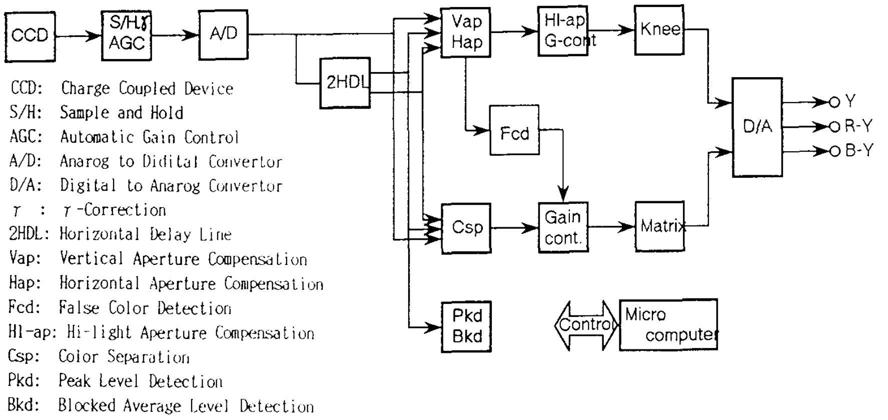


Fig. 10 Configuration of Video Camera

The white clipping is performed on each pixel signal by obtaining a corresponding clip value for each pixel level based on the white balance gain. The clip level CL(px) for each pixel can be derived by solving the following equations.

$$\begin{aligned} CL(Ye + Mg) &= \min(a,b)/a \\ CL(Cy + G) &= \min(a,b)/b \\ CL(Mg + Cy) &= \min(c,d)/c \\ CL(Ye + G) &= \min(c,d)/d \end{aligned}$$

By employing the above shown signal clipping method by which the signal clipping is made for each pixel, the point where a color difference signal is clipped at white can be brought up to a saturation level of each pixel signal. The gain of color difference signal is adaptively controlled by utilizing the level of YL and AGC gains like it was performed in the gain control made for the aperture compensation signal.

Fig. 13 shows a typical control characteristics where AGC is used as a control parameter. The adaptation of this method reduces the gain at the parts where substantial noise increases by the higher application of AGC and γ-correction are inevitable, and this reduces the noises also for preventing picture quality degradation.

5.2 LSI Developments

The above described functions are implemented into two newly designed LSIs. Table 3 shows a summarized specifications of these LSI chips of which photographs are shown in Fig. 14. The neg/pos switcher, signal word-length limiter, and title inserting functions are also implemented therein.

A 10,000 gate LSI with 14.4 K bit RAM is incorporated in DSP1, and a 15,000 gate processing circuit is incorporated in DSP2. Both LSIs are fabricated under a 1.5 micron design rule occupying approximately 58 mm^2 chip area.

Totally new unit function cells are developed specifically for digital signal processing for achieving higher integration order. Furthermore, dynamic flip-flops are employed in the signal processing circuits, and a dynamic RAM is employed for the 2H signal delay circuit. Both LSIs are driven by 13.5 and 15.75 MHz master clock signals respectively.

6. CONCLUSION

The saturation and glooming problems involved in present consumer-use video cameras caused by narrow dynamic range of single CCD camera system and lack of signal processing capability are solved by the methods developed by the authors.

One of the problems is solved by attaining detection of contrast level by analyzing the distributions of CCD signal levels independent of iris operations.

The adaptive control of signal processing characteristics to the object contrast level to compensate the narrow dynamic range is accomplished by the thus obtained contrast informations. This prevents excessive iris closing under back lighting and saturation of locally bright area of images produced by excessive forward lighting. An extension of the dynamic range by as much as 6 dB became possible by this.

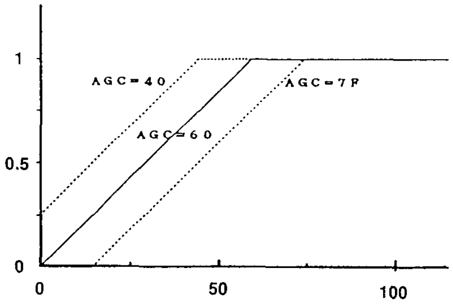
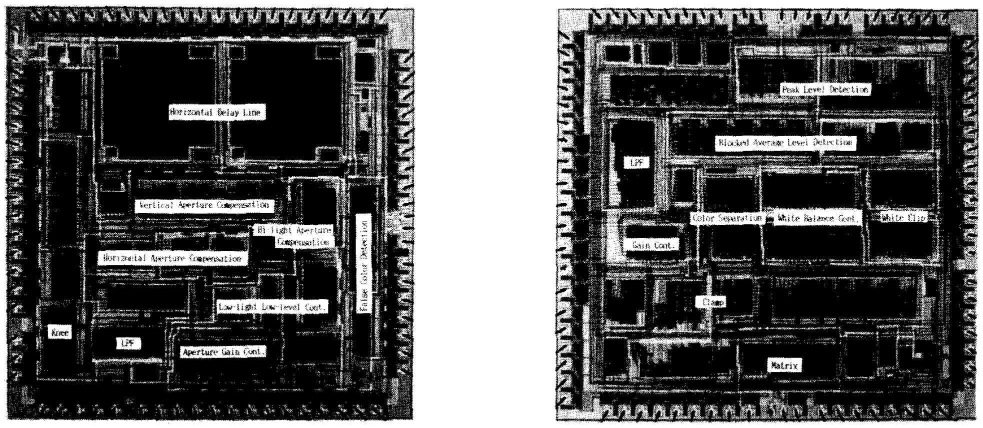


Fig. 13 Characteristics of color difference signal gain

Table 3 Specification of LSIs

LSI	Functions	Supply Voltage (V)	Power Consumption (mW)	Number of Elements (Gate)	Capasity of Memory (bit)
DSP1	2 Horizontal Delay Horizontal Aperture Compensation Vertical Aperture Compensation Auto Knee Correction Hi-light Aperture Compensation False Color Detection	5	310	10,000	14.4k
DSP2	Color Separation White Balance Control False Color Suppression Matrix Peak Level Detection Blocked Average Level Detection	5	260	15,000	—



DSP1 **DSP2**

Fig. 14 Overview of LSI chips

Furthermore, a new white balance control for minimizing discoloring effects by recording achromatic signals obtained under varying color temperature and fluorescent lighting is also developed.

Two LSIs incorporating these functions and those of other control circuits are developed and the effectiveness of these are experimentally confirmed.

7. ACKNOWLEDGMENT

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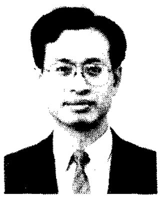

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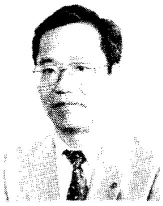

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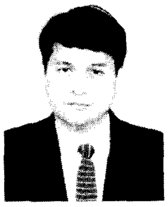

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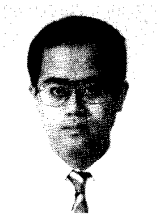

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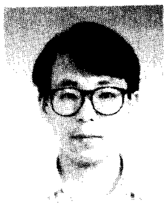

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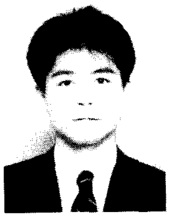

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