A New Conceptual Digital Still Camera

Kazuhiko Takemura, Manabu Hyodo, Kazuya Oda and Toru Nishimura
Electronic Imaging Products Div., Fuji Photo Film Co., Ltd.
Asaka, Saitama, Japan

Abstract

In recent years, the number of pixels employed in consumer digital still cameras is increasing dramatically, resulting in that over a half of the digital still cameras currently used in the market have over 2 million pixels. The image quality of consumer digital still cameras is almost compatible to that achieved by conventional silver-halide photographs in terms of resolution, graininess and color quality. However, to obtain higher image quality and to achieve improved robustness of picture quality, a digital camera capable of capturing a wider-dynamic range CCD has been greatly desired. In this paper, we review some important aspects to improve image quality of consumer digital still cameras and propose our new conceptual CCD, which enables capture of a wider dynamic range. The new technology to realize a wider dynamic is introduced and new algorithm to utilize the dynamic range is developed. Finally, a new conceptual camera which employs the newly developed CCD will be described.

Introduction

Digital still cameras are getting popular not only in the professional market but also in the consumer market. In recent years, the number of pixels employed in consumer digital still cameras is increasing dramatically, resulting in that over a half of the digital still cameras currently used in the market have over 2 million pixels.[1] Such trend is definitely based on the enormous advances in the field of fine electronic-device processing technology. The typical cell size of a pixel employed in the consumer digital cameras was over 3 micrometers in 2001, however, it is estimated that the size will be reduced in the middle of 2 micrometers in few years. In Figure 1, the trend of the number of effective pixels employed in consumer digital cameras is illustrated. It is expected that a digital still camera having 10 million effective pixels with 1/1.7 inch Charge Coupled Devise (CCD) will be available near future.

As the number of pixels increases, the ability to depict fine details is improved steadily. However, at the same time, the reduction in cell size is usually accompanied with some demerits such as increasing noise. Since the number of photons captured by a photodiode is decreased significantly according to the reduction of the size of the photodiode, it is necessary to increase gain to maintain the ISO speed setting constant, resulting in increasing noise level. Another disadvantage might be that as the number of pixels increases, the higher performance of optical lens will be required to realize higher resolution. The increase of pixels also requires users to prepare large memories to store images or to use high performance computers to edit or to manipulate images comfortably.

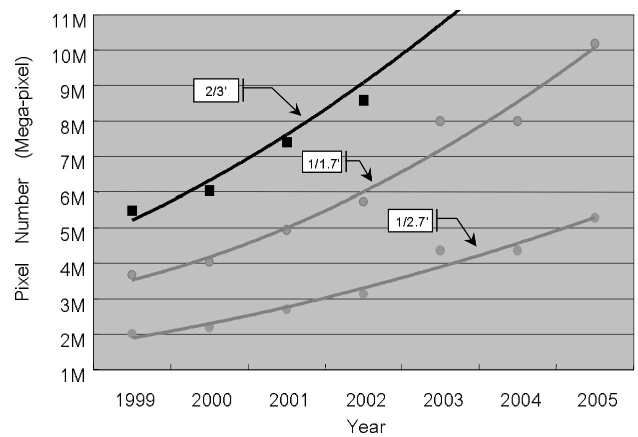

Figure.1 Trend of the number of pixels in consumer digital still cameras

On the other hand, the benefit of the increase of pixels is capable of depicting fine details. It is also useful to create large-size pictures or to apply electronic zooming. In Table 1, the number of pixels required to make various print size image is tabulated when print output is carried out by using Frontier Mini Lab Printer[2] with 300 dots per inch (DPI) . It is clear from Table1 that current consumer digital cameras seem to have adequate pixels as far as the resultant image is to be printed in up to 5x7 inch size.

Table 1. The Number of Pixels Required for Typical Photographic Print (M:million).

Print Size	Pixels	Total
3.5 x 5	1074 x 1523	1.63M
4 x 6	1228 x 1818	2.23M
5 x 7	1535 x 2137	3.28M
8 x 10	2433 x 3035	7.38M

The image quality achieved by consumer digital cameras has been steadily improving. Nowadays it is almost compatible to that achieved by conventional silver-halide photographs in terms of resolution, graininess and color quality. However, there still remains a noticeable difference between digital still cameras and conventional photographic systems. Figure 2 shows a characteristic curve of the green-layer obtained by a typical commercially available negative film. In Figure 2, a series of densities corresponding to gray patches of a Macbeth Color Checker chart when taken with the appropriate exposure level and processed properly is also plotted on the curve. It is found from Figure 2 that the negative color film can capture scene information over the range of 1000%. This is why the conventional photo system can reproduce the fine details of the highlights or specula-highlight well. Also it should be noticeable even though the scene was taken with 4 f-stops over-exposure level, the gray patches could be reproduced correctly by adjusting the exposure level onto a paper at the printing stage. This example shows that a wider dynamic range should be useful to make preferable prints from the data even when the exposure level is not exactly correct and consequently leads to the improving robustness of picture quality.

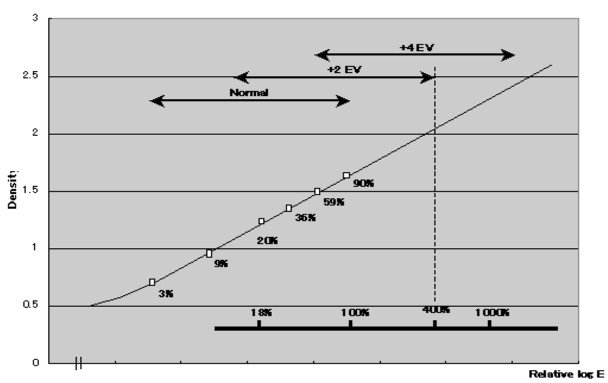

Figure 2. Characteristic curve of the green sensitive layer of typical negative film and its dynamic range

Therefore, a new conceptual digital still camera capable of capturing a wider-dynamic range makes benefits for consumers, who do not have enough skills for shooting pictures by digital still cameras.

Design of a New CCD

Many researches have been carried out to propose and realize a wide dynamic range of imaging sensors as well as methods to utilize a wide dynamic range.[3-7] Such researches include a well-known method to shoot two images successively by changing exposure levels and super-imposing them to make one final image. However, in this case, it is difficult to capture the moving image target. Therefore it does not fit for the consumer use. On the other hand, if a sensor device could capture sufficient enough photons and store them three times or four times as much as the current one, then a wider dynamic range could be realized. However, it is substantially infeasible under the situation that the size of CCD is limited and the number of pixels is getting larger year by year.

A color negative film is composed of three sensitive layers, typically blue-, green-, and red-sensitive layers. Figure 3 is a cross-section of such negative film. It is also found that each sensitive layer is composed of two or three layers. For example, a green-sensitive layer is composed of three layers that have different types and different sizes of silver-halide grains. A wide dynamic range of a negative film is accomplished by superimposing a high-sensitive layer, a middle-sensitive layer and a low- sensitive layer. Each of these sensitive layers captured the scene information corresponding to each of incident light intensities from a scene respectively.

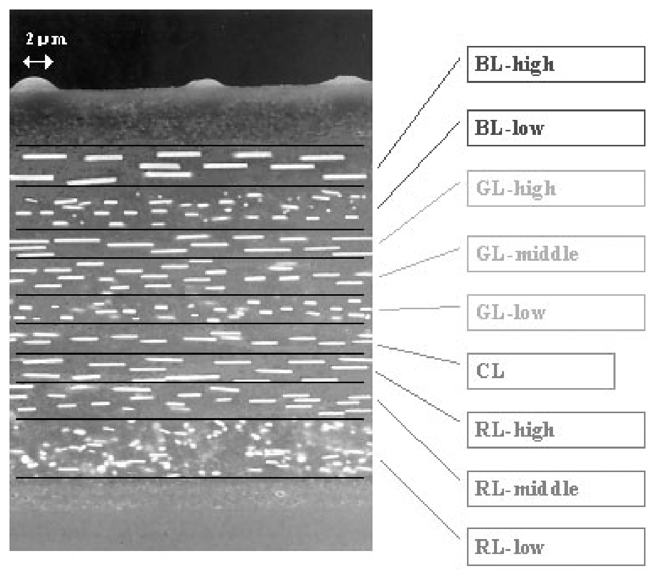

Figure 3. Cross section of a color negative film

We employed analogy to expand a dynamic range of a CCD. Figure 4 shows a sketch of a newly developed CCD. Its unique structure is that a pair of different photodiodes is arranged under a micro lens that is located on the top surface**.** A color filter is placed between the micro lens and a pair of photodiodes so that a pair of photodiodes can capture the same color information, blue-, green- and red-information.

Each of two photodiodes has a different size as shown in Figure 5. The larger one is dedicated to capture relatively lower light intensity information and the smaller one is dedicated to capture relatively higher light intensity information. Therefore, the larger photodiode is designed for high sensitivity and the smaller photodiode is designed for low sensitivity. Note that this unique structure in which the two different photodiodes are arranged under a micro lens is aimed to obtain the same spatial information. The sensitivity of a low-sensitive photodiode is set to about one sixteenth of that of a high-sensitive photodiode. The saturated level of the low-sensitive photodiode is set to about one third of that of the high-sensitive photodiode. Consequently, the dynamic range captured by the low-sensitive photodiode is more than 4 times wider compared to the high-sensitive photodiode. The relationships between relative illuminance and relative output voltage for both of photodiodes are illustrated in Figure 6.

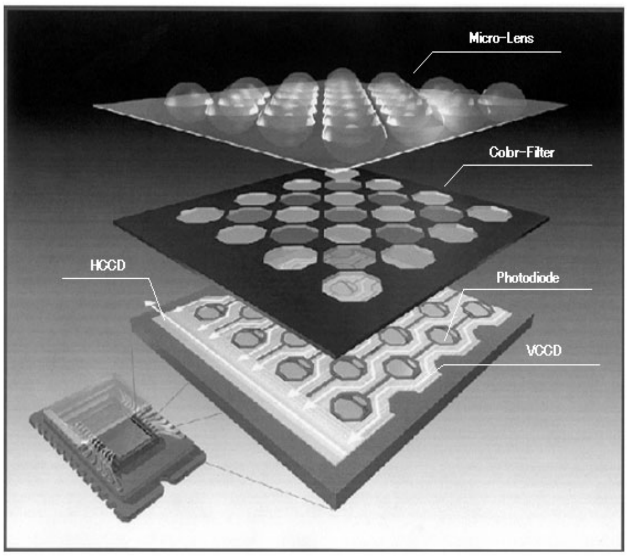

Figure 4. Sketch of a newly developed CCD

The two photodiodes is separated by a channel stop and each of photodiodes has a different gate. The gate of high-sensitive photodiode is connected to odd--numbered electrodes and the gate of low-sensitive photodiode is connected to even-numbered electrodes so that electrons stored in the high-sensitive photodiode and low-sensitive photodiode can be read out field by filed alternatively. Accordingly all electrons captured are transferred by vertical CCDs.

Since the two different photodiodes are arranged in a fixed cell size, one might think that the saturation of the high-sensitive photodiode will be decreased. We have successfully overcome this inherent disadvantage by applying the latest fine electronic-device processing technology, which is capable of reducing VCCDs width and spreading the size of the photodiodes. As a result, it is estimated that the saturation level is increased by 30% compared to the former type of CCD having the same cell size and the same effective number of pixels.

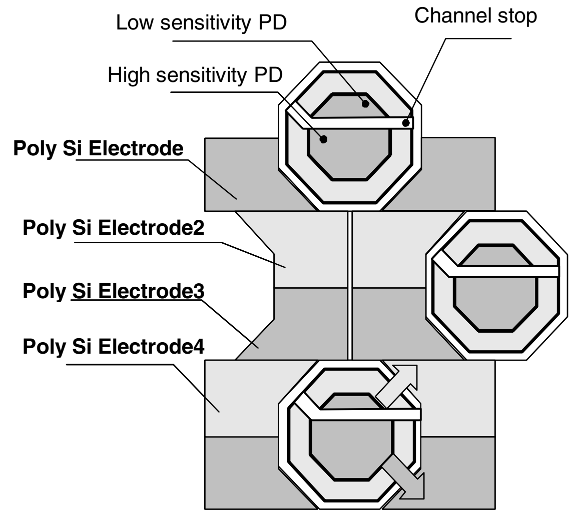

Figure 5. The layout of photodiodes and electrodes

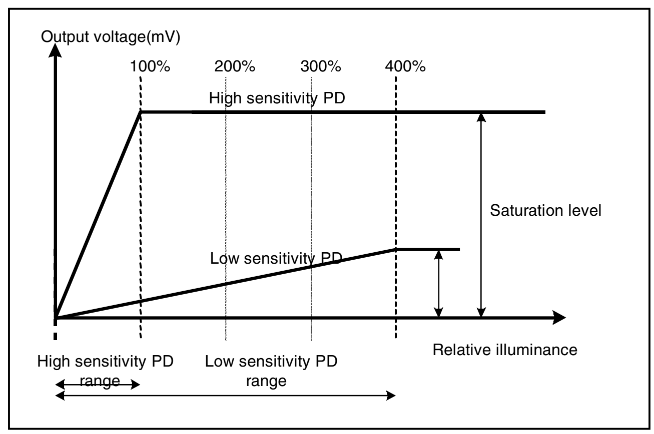

Figure 6. The relationships between relative illuminance and relative output voltages

Algorithm to Utilize the Wider-Dynamic Range CCD

It is obvious that a dynamic range of the scene depends on the weather condition or contents involved in the scene. It also depends on shooting conditions. In a sunny day, a camera with a wider dynamic range CCD will provide a benefit, since it can capture the wider light intensity range and depict it in a final image in which a smooth highlight gradation can be reproduced. If a picture is taken from a short distance by using a flash, a camera with a wider dynamic range CCD will be able to reproduce an image with a good face-tone gradation. On the other hand, in case of a cloudy day, the dynamic range of a scene is somewhat restricted. In such situation, a camera capable of capturing a wider dynamic range might not be necessarily required to avoid the resultant image becoming too soft or dull.

Likewise in case of typical indoor situations, a camera with a wider dynamic range CCD is not necessarily required.

These examples suggest that to achieve preferable tone reproduction against a wide range of shooting conditions, it should be required to determine the dynamic range to be captured according to the dynamic range of the scene first, then reproduce the final image by controlling the opto-electronic conversion function according to the captured dynamic range so that the final image could have the preferable gradation over the range.

To achieve this purpose, we developed the algorithm in which the dynamic range to be reproduced is judged and determined automatically, then build up a superimposed image having the preferable gradation curve corresponding to the scene conditions. The dynamic range to be reproduced can be determined by analyzing the information captured by the low-sensitive photodiodes. There are many possible ways how to superimpose to obtain a final image, however, we adopt the way that the high-sensitive information and the low-sensitive information are mixed after applying a different gamma to each of the information. This is mainly because of keeping good robustness for image quality. The composition ratios of the high-sensitive and the low-sensitive information are varied according to the dynamic range to be reproduced. The flow of the algorithm is shown in Figure 7 and the combined opto-electronic conversion functions are shown in Figure 8 respectively.

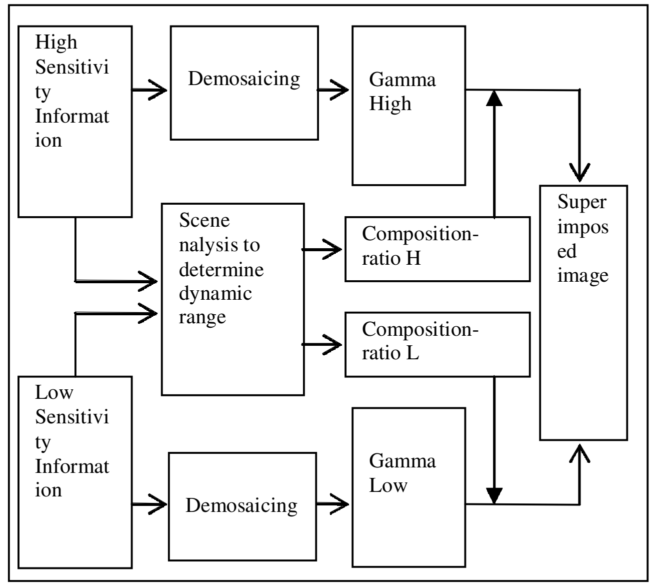

Figure 7. The flow of the algorithm to build up a final image

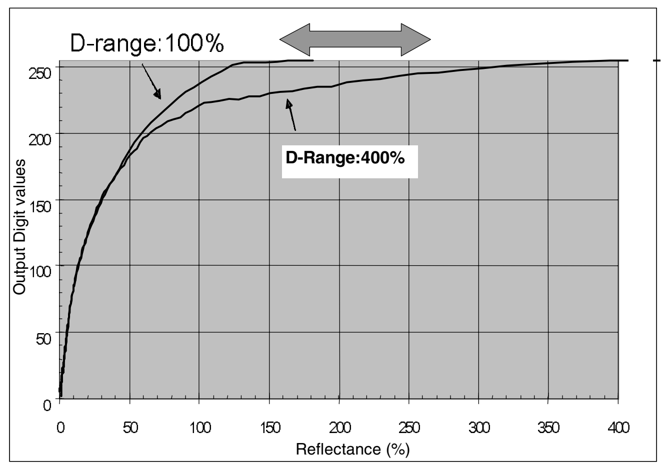

Figure 8. Opto-electronic conversion functions for combined images. Two examples, in case of 100% and 400%, are shown in the figure.

Newly Designed Digital Camera Specifications

We designed and developed a wide dynamic range CCD.

This prototype CCD has 1/1.7 inch size or 9.22 mm in diagonal direction. The total number of pixels is 6.66M (3.33M + 3.33M) and a unit cell size is 3.8 micrometers. Since a pair of photodiodes is dedicated to build up a cell, the number of cells contributed to form a final image is 3.33M. The main specifications are tabulated in Table 2. We intend that the camera system equipped with this prototype CCD can deliver higher quality images with the wide dynamic range up to 400%, which is equivalent to 4 times higher intensity than that of diffuse white. The system will also deliver better quality images even when a shot is made with 2 f-stops over-exposure unexpectedly. We also optimize the structure of micro lens so that the light efficiency is maximized to realize high ISO speed settings.

The main specifications of a prototype camera, which employs the prototype CCD described above, are tabulated in Table 3. This prototype camera is also applicable for motion picture shooting and capable of shooting 640 x 480 pixel motion pictures at 30 frames per second. This is achieved by introducing both vertical and horizontal skipped readout technology developed last year.

Table 2. Main Specifications of Prototype CCD

	Prototype CCD	
	High Sens. PD	Low Sens. PD
Device structure	Progressive / Interlace scan	
Chip size	9.15 x 7.80 mm	
Pixel size	3.8 micrometers	
Total pixel number	6.66 million (S pixel : 3.33 M R pixel : 3.33M)	
Color Filter	Green : Square Lattice Red & Blue : Mosaic	
Saturation Voltage	700 mv	250 mv
Sensitivity at 1200cd/m^2 5100K	400 mv	25 mv

Table 3. Main Specifications of a Prototype Camera

	Prototype camera
Effective pixels	6.2 million (S-Pixel :3.1million,R-Pixeel :3.1million)
Storage media	xD-Picture Card
File Format	Still: JPEG (Exif Ver.2.2) Movie: AVI format & Motion JPEG
Recorded pixels	Still image : up to 2832x2128 pixels Movie : up to 640 x 480 pixels 30 fps
Lens	Super EBC Fujinon 3x zoom lens Aperture:F2.8-F8(wide) F4.9-F14(Telephoto)
Focal length	7.7mm – 23.1 mm
Sensitivity	Equivalent to ISO160-400 (Auto) Equivalent to ISO200/400/800/1600*(Manual) *Resolution fixed at 1280 x 960

Conclusion

Although the newly developed fine processing technology can be applied to increase the number of pixels in consumer digital still cameras, we have challenged to employ it to expand a dynamic range of a CCD. A newly developed CCD, in which two different-sized photodiodes are arranged under a micro lens and worked as a high-sensitive photodiode and a lower-sensitive photodiode, has been designed and developed. The dynamic range of the CCD is expanded up to four times as wide as the former type CCD. We believe that a new digital still camera which employs this newly conceptual CCD accrues the fundamental benefit of the improved picture quality as well as the improved robustness of picture quality for consumers.

References

1. Web site at Camera and Imaging Products Association, http://www.cipa.jp/
2. N. Nakamura, Digital Image Processing for the Frontier 350Digital Minilab, Proc, IS&T's 1999 PICS Conference, pp. 96-99,1999
3. K. Takada, et al, Logarithmic-Converting CCD Line Sensor, J. ITE, 49, 2, pp. 169-175, 1995
4. Y. Oike, et al, High-Sensitivity and Wide-Dynamic-Range Position Sensor Using Logarithmic-Response and Correlation Circuit, IEICE Trans. Electron., E85-C, 8, pp. 1651-1658, 2002
5. M. Schanz, et al, "256x256 pixel CMOS Imager with Linear Readout and 120dB Dynamic Range ", Proc. 1999 IEEE Workshop CCD and Advanced Image Sensors, pp.17-20, 199
6. K. Yamada et al, "Wide Dynamic Range Vision Sensor", Toyota CRDL Review, 30, 2, pp. 35-44 (1995)
7. K. Ueda et al, A level-Conversion Method for Wide-Dynamic-Range Camera System, J. IIITE, 56, 3, pp. 469-475 (2002)

Biography

Kazuhiko Takemura received his M.S. degree in imaging engineering from Chiba University, Japan in 1982 and joined Ashigara Research Lab of Fuji Photo Film. Co.,Ltd. From 1994 to 1996 he joined Center for Imaging Science, Rochester Institute of Technology as a visiting scientist. He is now working at product planning & Development Div., Electronic Engineering Products Div. of Fuji and in charge of development of CCDs and image processing algorithms for digital still cameras. He is a member of the IS&T, JCIE and SPSTJ.