High quality image processing using one-dot-movement and re-sampling techniques

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Abstract

Image processing using one-dot-movement and re-sampling techniques has been developed in order to achieve high-quality color images. By shifting a CCD one pixel, two different raw images are captured and then image processing is used to easily produce a high-resolution color image. This type of color image has a higher frequency component than that obtained by conventional color interpolation. Furthermore, interpolation smoothing can be used to obtain an even higher quality image. As a result, the obtained image is as fine as the image captured by a CCD that has twice the number of pixels.

Introduction

Several manufacturers have released digital cameras that use CCD imager. It is believed that in the future digital cameras will replace film cameras. However, the resolution of digital cameras is lower than that of 35-mm film cameras. Since most users of digital cameras have been requesting feature that allows images with high resolution to be captured, many manufacturers plan to develop a new one when a higher-resolution CCD is released. The number of pixels has already increased from 300,000 to 2,000,000, and this year a 3,000,000-pixel digital camera will be released for consumers.

However, digital cameras with such a high-resolution CCD are too expensive for most consumers. Thus, a high-resolution imaging system with a lower-resolution CCD is needed. This paper describes such type of imaging system which does not need to use a CCD with an increased number of pixels.

Digital camera's configuration

The configuration of a conventional digital camera is shown in Fig 1. An image of an object is produced on a CCD by the lens. And a mechanical shutter or iris controls the exposure of the image. The optical filter consists of an IR cut filter and an optical low-pass filter. The IR cut filter removes infrared rays that distort color information. The optical low-pass filter removes frequency components in the image that are higher than NYQIST.

The CCD converts the optical image into an electrical signal in order to create the digital image. The digital camera uses a color CCD that has mosaic-type color filter in order to obtain color information. And, the front-end converter converts the electrical signal into a digital image. This digital image is called a raw image since it does not contain color data in each pixel. After receiving the raw image, the image processor creates an RGB image that contains R, G, and B data in each pixel by creating missing data by interpolating the same color data from neighboring pixels.

Conventional digital cameras with this type of configuration create the RGB image from the object image. However, the resolution of this artificially created RGB image does not correspond to the CCD pixels due to the use of the color interpolation. This purpose of our work is to create a high-resolution image with the same number of CCD pixels without using color interpolation.

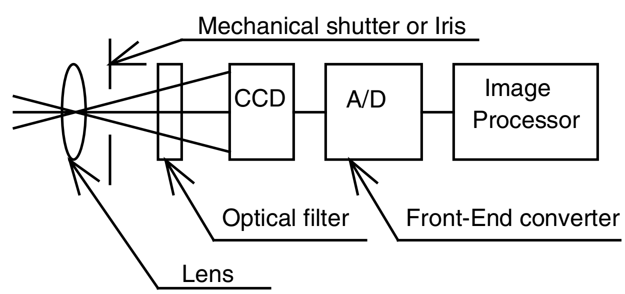

Figure 1 Digital camera's configuration.

One dot movement mechanism

The one-dot-movement mechanism is one of the unique features of the camera we have developed. This mechanism enables a high-quality image to be created from two raw images, as shown in Fig. 2. A piezo-laminated actuator extends 60 nm per 1 volt. When voltage is applied to the actuator, the CCD will move within about one millisecond or less. The CCD moves exactly one pixel pitch The CCD needs to be moved at the end of the first exposure and start of the second exposure in order to obtain the two raw images, as shown in Figs. 5 (a) and (b).

There are two types of double-exposure systems: The first type uses a half-frame CDD and mechanical shutter. This type is used in conventional digital cameras for single exposures and has a long exposure interval since data must be transferred until the next exposure. The second type uses a full-frame CDD and mechanical shutter. This type has a shorter exposure interval but is more expensive than a half-frame CCD.

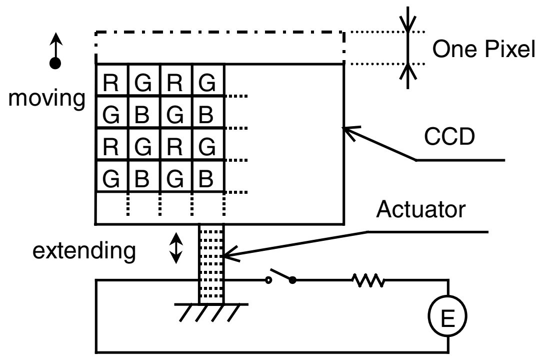

Figure 2 One-dot-movement mechanism.

A timing chart for a full-frame CCD is shown in Fig. 3. An electronic shutter signal is used to discharge electrons charged during exposure. The first exposure begins at the end of electronic shutter signal and finishes at the transfer timing, and then the first image signal is transferred to the front-end converter in order to produce the digital image. Then the actuator moves CCD one pixel at time. The second exposure starts at the end of the electronic shutter signal and finishes when the mechanical shutter closes. Then, the second image signal is transferred, and as a result, two images can be captured in a short interval. Therefore, the one-dot-movement mechanism can obtain two raw images by only slightly shifting the CCD. The creation of the color image is described in the following section.

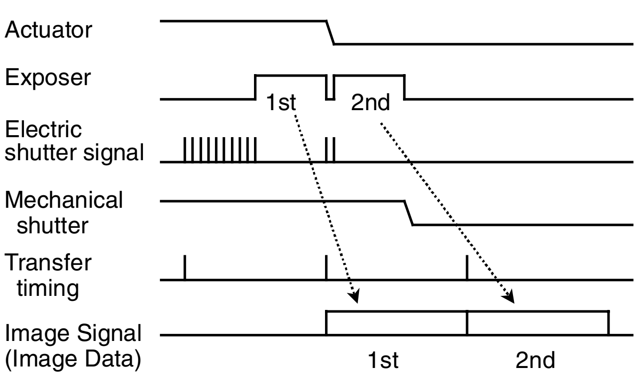

Figure 3 Timing chart of using full frame CCD.

Image processing

The flow chart of this image processing is shown in Fig. 4. The one-dot-movement mechanism obtains the 1st and 2nd images of the raw images, as shown in Figs. 5(a) and (b). First, exposure-difference correction corrects the signal level difference between the first and second exposures if the exposures differ. This process is explained in detail below:

The averages of Image 1 and Image 2 are calculated. And then two corrective raw images are created by applying equations 1 and 2.

$$\text{Image1} \quad d_i = d_i \cdot Ave0/Ave1 \qquad (1)$$

$$\text{Image2} \quad d_i = d_i \cdot Ave0/Ave2 \qquad (2)$$

d_i is data of Image 1 or Image 2, Ave1 and Ave2 are the averages of the two raw images, and Ave0 is the average of Ave1 and Ave2. This exposure difference of the two raw images can be revised by applying this correction.

Full RGB processing creates a high-resolution color image from Image 1 and Image 2, which is then corrected by using exposure-difference correction. After a high-resolution color image has been created, the re-sampling processing magnifies the image 1.5 times by using interpolation in order to increase the image quality. The re-sampled image is smoother than other high-resolution color images because there is less aliasing found in the digital image.

Gamma processing, YUV processing and JPEG compression make JPEG image in order to store image in memory card and others. These three processes use a conventional algorithm.

As a result, high quality image is created from two raw images, since the re-sampled image is high resolution and less aliasing. The details of full RGB processing and re-sampling processing are described in the following section.

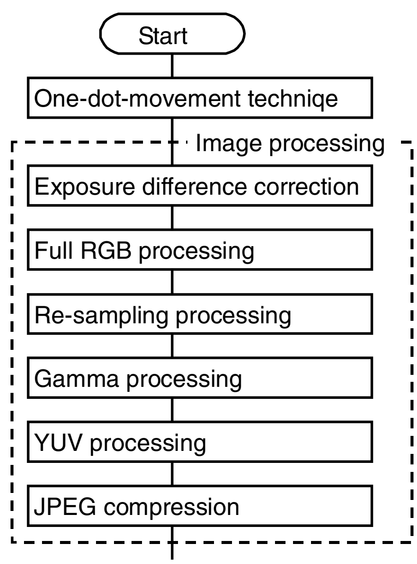

Figure 4 Flow chart of image processing.

Full RGB processing

The one-dot-movement technique is shown in Figs. 5 (a) and (b). The second image is the same as the first image and is only vertically shifted one pixel. These images can be replaced with the image shown in Fig. 5 (c). G data exists in each pixel in this image and R or B data exists only in every other column. Therefore, the missing R or B data need to be created in order to create a full RGB image by correlation. For example, the missing R data of the target position is created, as shown in Fig. 5(c).

First, the G data of the neighboring position and of the target position are correlated, as show in Fig. 5 (c). Equation 3 is used to detect the correlation.

$$\textit{Correlation} = ABS\ (\ G_{Target} - G_{Neighboring}\ ) \qquad (3)$$

Next, the position of highest correlation is detected in the neighboring G data. The missing R data is created from the data of the detected position. (This data is actually substituted for the missing data). The missing B data can also be calculated in the same way. All the RGB values of the image can be made by repeating this process for all positions.

As described above, the one-dot-movement technique can obtain a full G image and half R B image. And full RGB processing can create missing R B data easily without using complicated color interpolation since G data exists in every position. And also full RGB processing creates missing R B data by the correlation of existent G data instead of interpolation. In addition, since G data exist in every position, a high-resolution color image can be obtained.

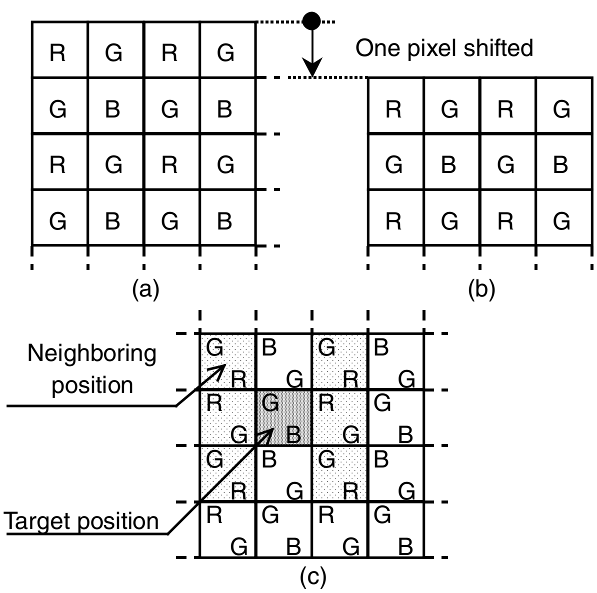

Figure 5 Color image of Full RGB processing:

(a) 1st image, (b) 2nd image, and (c) 1st and 2nd Image.

Re-sampling Processing

In order to increase the quality of the image, the interpolation function is used to magnify the image 1.5 times. The interpolation function usually uses cubic convolution. In this case, a special interpolation function is used since this processing executes aperture correction and re-sampling simultaneously.

Conventional re-sampling processing with an arbitrary scale factor is shown in Fig. 6. Equation 4 shows how this process is calculated.

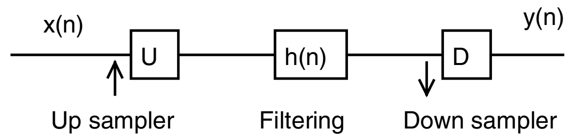

Figure6 Block diagram of re-sampling.

$$y(n) = \sum_k x(k)h(Dn - Uk)$$

$$\textit{Scale-factor} = U / D \qquad (4)$$

In this case, U is 3 and D is 2 since the scale-factor is 1.5. An up sampler creates 3-times the amount of data by using a function that inserts a zero into the parts that do not contain any data. Filtering is used to transfer data by applying an interpolation function that maintains the frequency bandwidth of the original data, as shown in Fig. 6. A down sampler makes half the data by down sampling. This type of processing can be used to make a re-sampled image. However, this type of processing is somewhat redundant since part of the input data (marked zero) and the down-sampled output data do not need to be calculated. A more practical type of processing is shown in Fig. 7. When cubic convolution is used as an interpolation function, the filter has at most 4 taps, as shown in Fig. 7. And the transfer function of this filter is shown in equation 5.

$$H(Z) = m_0 + m_1 \cdot Z^{-1} + m_2 \cdot Z^{-2} + m_3 \cdot Z^{-3} \qquad (5)$$

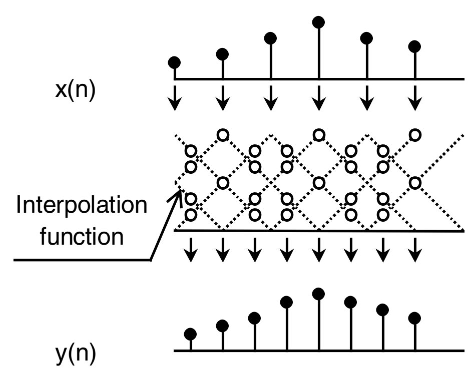

Figure 7 Re-sampling by using the interpolation function.

Aperture correction corrects an image for a decreased frequency component by using the pixel aperture or color interpolation. The aperture correction uses the transfer function that is shown in equations 6 and 7.

High correction $$H(Z) = a_0 + a_1 \cdot Z^{-1} + a_2 \cdot Z^{-2} \quad (6)$$

Mid correction $$H(Z) = b_0 + b_1 \cdot Z^{-2} + b_2 \cdot Z^{-4} \quad (7)$$

High-correction usually corrects an image that has a decreased high-frequency component due to the pixel aperture. Mid-correction usually corrects an image that has a decreased mid-frequency component due to the color-interpolation.

As described above, the full RGB process can create an image without decreasing the mid-frequency component during color-interpolation. Therefore, the filter used for interpolation is only a 3-tap filter since the aperture correction does not need to enhance mid-frequency component. The 6-tap filter from h0 to h5 is necessary for conducting aperture correction and re-sampling since the aperture correction filter uses 3 taps and the re-sampling filter uses 4 taps, as shown in Fig. 8. However, a 4-tap filter from k_0 to k_3 is practically sufficient since usually a_0 and a_2 are smaller than a_1, and m_0 and m_3 are smaller than m_1 or m_2, h_0 (that is a_0 multiplied by m_0) and h_5 (that is a_2 multiplied by m_3) are small enough to ignore. Therefore, this transfer function is shown in equations 8.

$$H(Z) = K_0 + K_1 \cdot Z^{-1} + K_2 \cdot Z^{-2} + K_3 \cdot Z^{-3} \quad (8)$$

When this 4-tap filter is used, the re-sampling processing can be carried out in a short time. And the re-sampled image can be made by applying this filter to all image data.

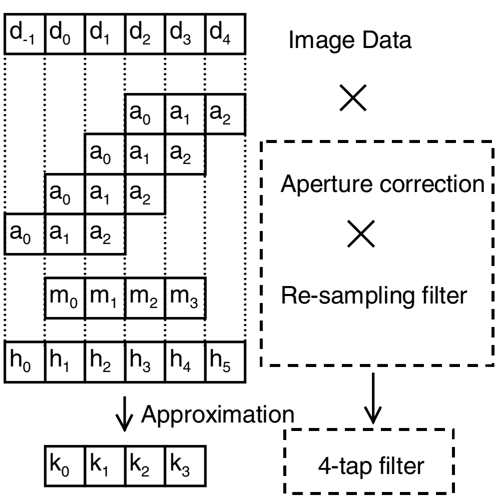

Figure 8 Digital filter.

Effect of processing

Images of resolution chart are shown with a 3-million pixel CCD (2048*1536) in order to illustrate the processing effects obtained by the one-dot-movement and re-sampling techniques. Fig. 9 shows a comparison between (a) the normal image using conventional image processing and (b) the image processed by one-dot-movement and re-sampling techniques. The normal image has a maximum resolution of about 1100 TV lines. The one-dot movement image has a maximum resolution about 1500 TV lines. And a one-dot-movement image, which is 1.5-times as large as the normal image, is smoother than the normal image. These result means that these techniques can be used to produce an image that is equivalent to one obtained by a CCD with twice as many pixels.

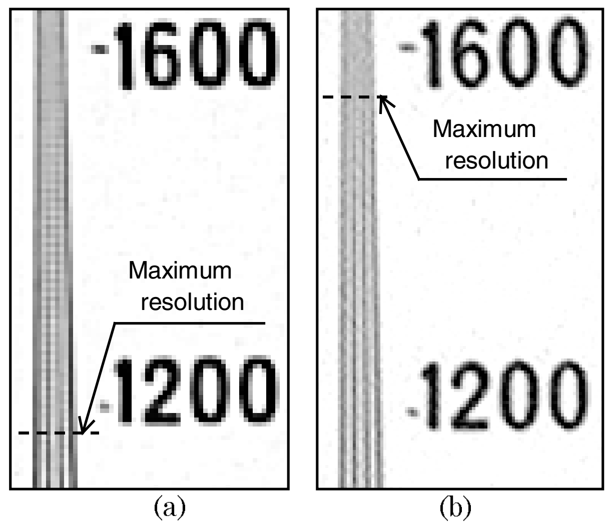

Figure 9 Final images.

(a) Normal image, and (b) One dot movement image.

Conclusion

A high-quality color image can be quickly produced by these techniques since this full RGB processing and re-sampling processing are very simple. However, a digital camera that uses these techniques can not be easily applied for moving objects, but in the future, these techniques will be able to be used with systems that contain two CCDs that can capture two images at the same time.

References

1. S. Arimoto , 'Signal and Image Digital Processing" [p. 146-].
2. T. Andoh ,'Fundamentals of Digital Imaging" [p. 115-].