

The Development of 1M-Pixel Digital Still Camera

Naruo Takizawa, Jun Takayama and Po-Chieh Hung
Central Research Laboratory, Konica Corporation
Tokyo, Japan

Abstract

The Q-M100 1MB-pixel digital still camera was designed to satisfy the growing demand for a compact, high-quality, low-cost digital still camera. To reduce both size and cost, the camera uses a 1/3-inch CCD capturing device. All image processing is performed by software running on a DRAM-embedded RISC-MPU whose high-speed bus provides high-speed memory access. Because software processing is used in place of hardware processing, the image processing algorithms were designed to serve the camera, and not vice versa. Further, calculation speed was boosted by simplifying the algorithms used. Without sacrificing image quality, capture-to-storage times of 7 seconds for a 1152x872 image and 3 seconds for a 576x436 image were attained.

Introduction

Digital still cameras (DSCs) were first used for image input almost exclusively by personal computer buffs, but with the emergence of low-cost, easy-to-use, stand-alone color printers, general consumers have now begun to use DSCs much as they have traditionally used film cameras. The Q-M100 was developed to satisfy these new consumers' demand for affordable, high-quality DSC performance. A concise outline of the features offered by the Q-M100 are found in Table 1.

Using software supplied with the camera, many of the Q-M100's functions can be customized to meet user preferences, as seen in Table 2. For example, the bit rate control can be turned off to automatically match image file size to the nature of a given image, or turned on to simplify file management. Similarly, users can select those exposure control, white balance, gamma, sharpness, and saturation settings which serve them best.

Beyond this flexibility, however, is the central feature of high-quality image capture in a compact, low-cost camera. To provide this, the Q-M100 uses a 1M-pixel, 1/3-inch CCD with a complementary color filter. A complimentary filter was chosen over a primary color filter to take advantage of the superior sensitivity and resolution that a complementary color filter provides, and, unlike the 2x4-pixel color filter arrays prominent in digital video cameras, the Q-M100 uses a 2x2-pixel pattern that reduces moiré (Fig. 1).

Table 1: Q-M100 Specifications

Feature	Specification
Shooting modes	Normal, self-timer (10 sec), close-up, 4-frame continuous shooting, 2x digital zoom
Viewfinder	Real image type
Lens	Fixed focal length, f=6.0mm, F=2.8 (Equivalent to 39mm for 35mm camera)
Diaphragm mechanism	Two diaphragm blades driven by Step motor (F2.8, F5.6, F11) Shutter speed: 1/8 to 1/500 sec
Image device	1/3" CCD, 1.09M pixels
Object distance	0.2m to infinity Close-up mode: 0.2m to 0.8m
Focus control	Full range auto focusing
Exposure control	Program AE
Flash	Built-in automatic flash Effective distance: 0.5 to 3.0m, 5800K
White balance	Focal plane auto white balance
Image size	1152x872 or 576x436
Data structure	YCbCr420
Data compression	JPEG (Exif)
Data compression mode	SUPER FINE (10 frames at 4 MB) FINE (20 frames at 4 MB) ECONOMY (50 frames at 4 MB)
Storage media	CF card
LCD monitor	1.8" color LCD
Output	Serial I/F: RS-232C or RS-422 Video I/F: NTSC or PAL
Power Supply	4 AA-size alkaline, Ni-Cd alkaline, or Ni-H batteries, or AC adapter

Table 2: Customizable Functions

Function	Mode
Bit Rate Control	OFF / ON
Exposure Control	Multi Area AE / Spot AE
White Balance	Auto / Incandescent / Daylight / Strobe
Gamma	Default:2.2 / Macintosh:1.8
Sharpness	0 / 1 / 2 / 3 / 4
Saturation	1 / 2 / 3

G	Mg	G	Mg
Ye	Cy	Ye	Cy
G	Mg	G	Mg
Ye	Cy	Ye	Cy

Figure 1: Color filter array on the CCD

Overview: Image Capture, Processing, Storage, and Transmission[1]

The heart of the Q-M100's high-quality, low-cost performance is the camera's system of image capture, processing, storage, and transmission, featuring its 1/3-inch, 1MB-pixel CCD, a 2MB DRAM-embedded RISC-MPU, and fully software-based image processing (Fig. 2).

The optical image received by the CCD is fed to a CDS-A/D circuit, where noise in the CCD output signal is reduced using a CDS (correlated double sampling) circuit and the analog signal is converted to 10-bit digital data by an A/D converter.

This digital data is fed through the I/O ASIC to the RISC-MPU, where a high-speed bus carries it to the integrally mounted DRAM. Utilizing software residing in the flash ROM, the data is processed here to provide for AE (auto exposure) and AF (auto focus), and to supply JPEG image data for storage on a CF card and LCD image data.

The JPEG image data stored on the CF card is fed through the I/O ASIC for transmission via RS-232C or RS-422 ports and for expansion in the RISC-MPU's DRAM. The expanded data is fed back through the I/O ASIC and the video I/F for LCD or TV display.

Especially relevant to the system's exceptional speed is that all image processing is performed by software and running on the DRAM-embedded RISC-MPU. The high-speed bus between the RISC-MPU and the DRAM provides high-speed memory access, and because software processing is used rather than hardware processing, the algorithms involved are designed to match the camera, and not vice versa. Thus, without sacrificing image quality, the system provides capture-to-storage times of 7 seconds for a 1152x872 image and 3 seconds for a 576x436 image.

Image Processing

Of the steps outlined above, image processing design was perhaps most problematic, for a key objective was to reduce noise in the high-resolution image while maintaining high calculation speed. This was a challenge because of the S/N ratio of the small-pixel 1/3-inch CCD and the use of a complementary color filter.

Central to the solution was the development of an image processing algorithm based on digital video camera technology. Image processing was divided into two parallel process flows: the generation of color-difference data and the generation of luminance data (Fig. 3).

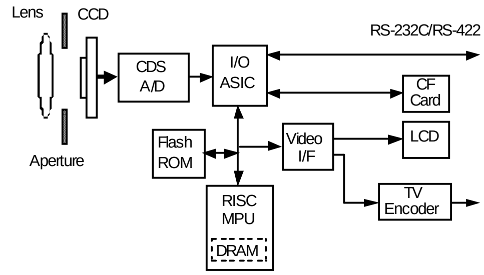

Figure 2: Image capture, processing, storage, and transmission

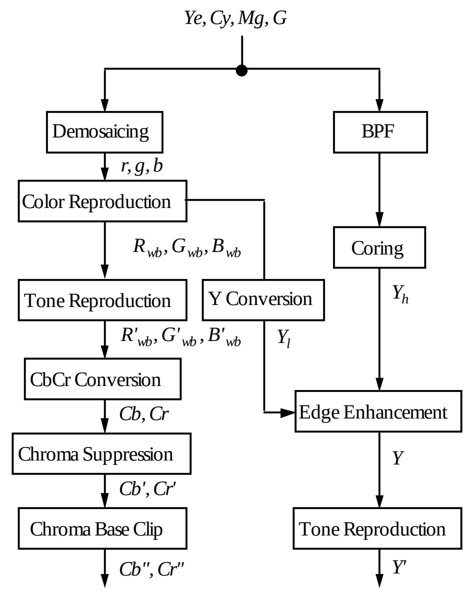

Figure 3: Image Processing steps

Generating Color-Difference Data

The first step in generating color-difference data is demosaicing. Because the Q-M100 uses a color mosaic filter, RGB data is interpolated from the Cy, Mg, Ye, and G data provided by the CCD pixels. In the 5x5-pixel area that surrounds any given target pixel, the average value of each filter color element is calculated and the average values are then converted to r, g, b as shown in equation (1) and (2).

$$\begin{bmatrix} R \\ B \end{bmatrix} = \begin{bmatrix} 1 & 1 & -1 \\ -1 & 1 & 1 \end{bmatrix} \begin{bmatrix} \overline{Ye} \\ \overline{Mg} \\ \overline{Cy} \end{bmatrix} \tag{1}$$

$$G = \overline{G} \tag{2}$$

Next, color reproduction and white balance are simultaneously determined through the application of a 3x3 color matrix, a method which significantly improves calculation speed. Based on a Macbeth ColorChecker and determined by regression, the matrix is automatically chosen from two matrices (one for incandescence and one for daylight), depending on the captured image. White balance is adjusted in order to maintain gray. After estimating the color temperature of the captured image, the color matrix is multiplied by a set of parameters, and the results form the basis of both tone reproduction and Y conversion.

In tone reproduction processing, an LUT (look-up table) converts the 10-bit image data to JPEG-compatible 8-bit data, and the tone curve is adjusted according to the image being processed. For example, the tone curve illustrated here (Fig. 4) would apply to a low-contrast image. This curve is based on gamma 2.2, and the curve is modified in order to expand contrast, with the shoulder used to avoid highlight saturation, and the gentle slope at the toe used to reduce noise in shadow areas.

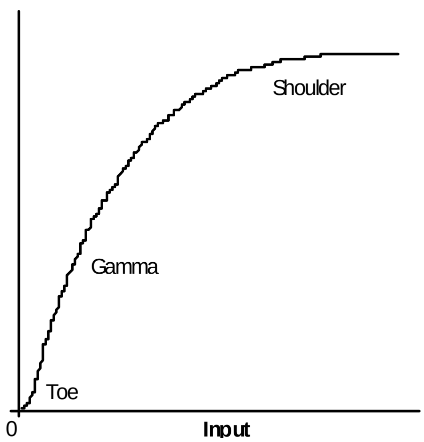

Figure 4: Tone curve for low-contrast image

In the next step, RGB data is converted to *CbCr* using equation (3), which is based on CCIR Rec.601[2].

$$\begin{bmatrix} Cb \\ Cr \end{bmatrix} = \begin{bmatrix} -0.1684 & -0.3316 & 0.5000 \\ 0.5000 & -0.4187 & -0.0813 \end{bmatrix} \begin{bmatrix} R'_{wb} \\ G'_{wb} \\ B'_{wb} \end{bmatrix} \quad (3)$$

In the final two steps, chroma suppression reduces color noise in shadows and highlights, and chroma base clip reduces color noise in gray.

Generating Luminance Data

The first step in generating luminance data is applying a BPF (band pass filter) to the Cy, Mg, Ye, and G data provided by the CCD pixels (Fig. 5). This generates high-frequency luminance data. Filtering is accomplished through convolution calculation, a method which would ordinarily result in low calculation speed. However, by using the average values derived from equations (1) and (2) above, high-speed calculation is obtained. Coring is then performed to reduce high-frequency noise.

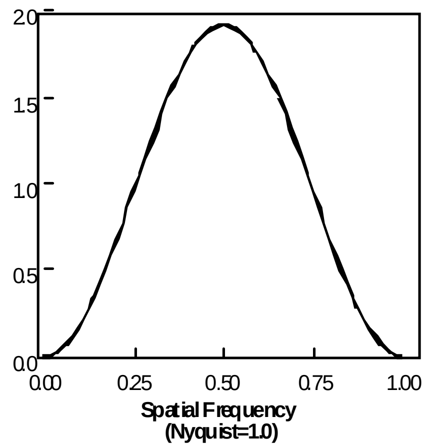

Figure 5: BPF spatial frequency

As noted earlier, the color reproduction and white balance data $R_{wb}G_{wb}B_{wb}$ is also fed to a Y conversion step. In Y conversion, equation (4) is used to convert this data to low-frequency luminance data Y_l. Like equation (3), equation (4) is based on CCIR Rec.601[2].

$$Y_l = 0.2990 \bullet R_{wb} + 0.5870 \bullet G_{wb} + 0.1140 \bullet B_{wb} \quad (4)$$

The low-frequency luminance data provided by Y conversion and the high-frequency luminance data provided by the BPF and coring are now used to perform edge enhancement, as shown in equation (5),

$$Y = Y_l + \alpha \bullet Y_h \quad (5)$$

where α is the sharpness parameter. Increasing α increases sharpness, but because it also tends to increase noise in shadow areas, the value of α for a given image is controlled by the luminance data for that image. The result is optimally increased sharpness and reduced noise.

In the final step, tone reproduction processing is performed precisely as it is when generating color-difference data.

Conclusion

The simplified algorithm made possible by the Q-M100's software-based image processing provides the speed and power to reduce noise, sharpen images, and maintain faithful color in a compact, low-cost DSC.

References

1. M.Takakuwa, J.Takayama and K.Nagaishi, "ASICs for megapixel digital still camera Q-M100", *KONICA TECHNICAL REPORT*, **11**, pp.71-76(1998).
2. CCIR Rec.601, "Encoding parameters of digital television for studios."