# Image-processing techniques for a consumer video printer

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***Abstract*** — The image-processing techniques used in a newly developed video printer are described. The amount of image data is reduced by subsampling the chrominance signals and by data compression. The DPCM algorithm is used for the compression. A field-interpolation algorithm that takes into account the correlation between diagonal dots is proposed. This algorithm is simple and has better spatial-frequency characteristics than the bi-linear interpolation algorithm. A color-signal-conversion circuit that enables users to adjust the color, tint, contrast, and luminance after capturing an image is also described.

***Keywords*** — *Color video, hard copy, image compression, video image capture.*

## 1 Introduction

There is an increasing need to obtain color hard copies of video signals from high-image-quality video equipment such as S-VHS VCRs and Hi8 camera-recorders. Of the various non-impact printing systems, the sublimation dye thermal transfer process is the most suitable for a consumer video printer because the printing process is simple and offers the possibility of providing an excellent photographic image. Several video printers have already been developed,[1-3] but these printers are not yet widely used. The main reason for this is that the image quality based on video signals is low compared with that of photography.[4] Other reasons are that image-processing techniques are not used sufficiently to enhance the image quality, the cost is high, and it is difficult to obtain a satisfactory print.

For consumer video printers that are mainly used at home, we consider the following points to be very important:

(1) Image data may be reduced, but subjective image quality must not be degraded.
(2) An advanced field-interpolation algorithm should be used for moving pictures.
(3) Color data should be converted after capturing an image because any color-conversion algorithms from the RGB (red, green, blue) data of a color television system to the CMY (cyan, magenta, yellow) data of a color printer are imperfect at present. This approach allows for several attempts to improve the final image quality.
(4) Image-processing techniques should be fully used to enhance image quality.

We have developed a new consumer video printer which features high image quality, ease of operation, and compactness. Digital image processing is used to improve the image quality, and the flexibility of digital processing also contributes to the ease of operation. Moreover, data-reduction techniques allow for the possibility of minimizing the total size of both image-memory and image-reduction circuits.

The digital image-processing techniques used in the printer are:

(1) Data reduction of chrominance signals.
(2) A field-interpolation algorithm that takes into account the correlation between diagonal dots.
(3) Color conversion from Y, R–Y, and B–Y (luminance and chrominance) data to CMY data after capturing an image.
(4) Horizontal and vertical edge enhancement.

This paper describes the system configuration and these techniques.

## 2 System configuration

The specifications of the video printer are shown in Table 1 and the circuit block diagram of the system is shown in Fig. 1. The system consists of a video interface, a data-compression processor, an image memory, an image processor, a print-engine processor, and a thermal head.

The video interface accepts both NTSC composite video signal and Y/C separate signals and decodes them to analog Y, R–Y, and B–Y signals. Then, the analog Y, R–Y, and B–Y signals are converted to digital Y, R–Y, and B–Y data, and transferred to the data-compression processor. Y, R–Y, and B–Y are the luminance and chrominance representations of the NTSC's primary colors.

**TABLE 1** — Specifications of the printer.

| | |
|---|---|
| Printing system | Thermal dye transfer |
| Video inputs | NTSC composite and S |
| Print area | 88 × 115 mm |
| Resolution | 5.4 dots/mm |
| Gray level | 128 levels / color |
| Dimensions | 420 × 110 × 350 mm |

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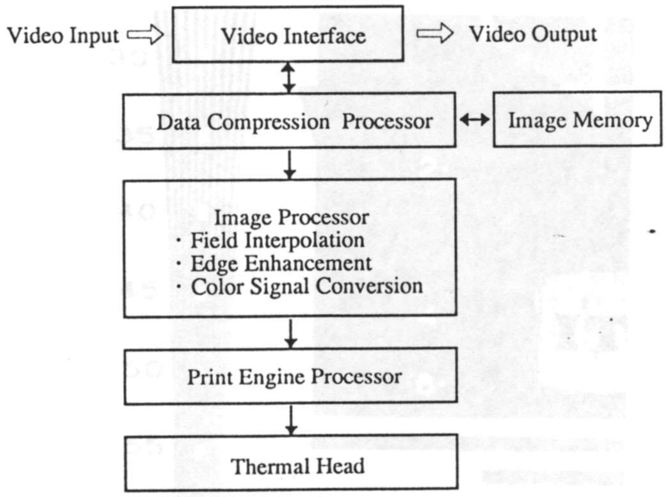



**FIGURE 1** — Circuit block diagram.

When capturing an image, the data-compression processor compresses the Y, R–Y, and B–Y data and stores them in an image memory. When printing the image, the data-compression processor decompresses the data in the image memory and transfers the data to the image processor. The decompressed image data are also transferred to the video interface for display on a television monitor. A complete image, called a frame, consists of two interlaced fields in the NTSC system. As the printer captures a frame, users can print an image from either the complete frame or one field.

The image processor interpolates the field image and, if necessary, enhances the sharpness and converts the Y, R–Y, and B–Y data to CMY data. The print-engine processor receives the print data from the image processor and controls the tone and gray balance of the picture through a thermal head. The heat energy generated at the thermal head is controlled by the pulse-width modulation (PWM) method.

## 3 Image processing for the video printer

### 3.1 Data reduction

As roughly estimated in Table 2, the amount of data required for an image is closely related to the image quality and the color model. In the estimation, it is assumed that the analog signals are digitized with 8-bit precision, the bandwidths of the RGB signals, the Y signal, and the composite video signal are 4.2 MHz; and the bandwidths of the R–Ys and B–Y signals are 1.5 MHz. For the consumer video printer, good image quality must be achieved at a price low enough for consumers. Among the three models the composite video model has the smallest size but the image quality is the worst because quantization error in digitizing the composite video signal causes Y/C separation error and color shift. Moreover, this model has difficulty in adapting to the Y/C separate input. The only way is to add the Y/C signals in the memory or to freeze the image at the video equipment connected to the printer. The Y · R–Y · B–Y model has an intermediate data size, while the image quality is the same as that of the RGB model. If the image qualities are the same, the less the amount of data, the better. Therefore, the Y · R–Y · B–Y model has the best balance for consumer use.

**TABLE 2** — Comparison of color models.

| Color Model | Data Size | Image Quality |
|---|---|---|
| RGB | large | good |
| Y · R–Y · B–Y | intermediate | good |
| Composite Video | small | bad |

The amount of image data can be reduced in two steps. The first step is to minimize the number of samples of the input video signals. The second step is to compress the sampled image data. The degradation of image quality should be avoided in either step because the human visual system is very critical for still pictures.

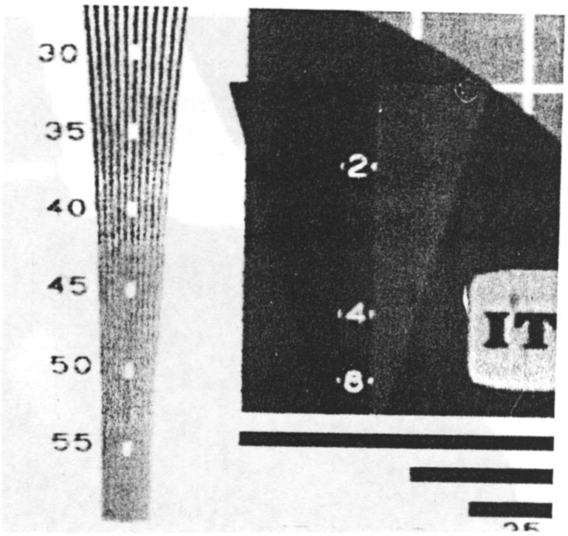
According to NTSC standards, the number of effective vertical lines ($V$ - no) is 485 and the effective horizontal period ($H$ - period) is 52.5 μs. The aspect ratio of the television monitor ($r_{TV}$) is 4:3 and the ratio of the width to the height of a dot of the printer ($r_p$) is 1:1. The horizontal dot frequency of the printer ($f_d$) is determined to be 12.3 MHz from the following equation:

$$f_d = (V - \text{no} \times r_{TV} / r_p) / H - \text{period}. \quad (1)$$

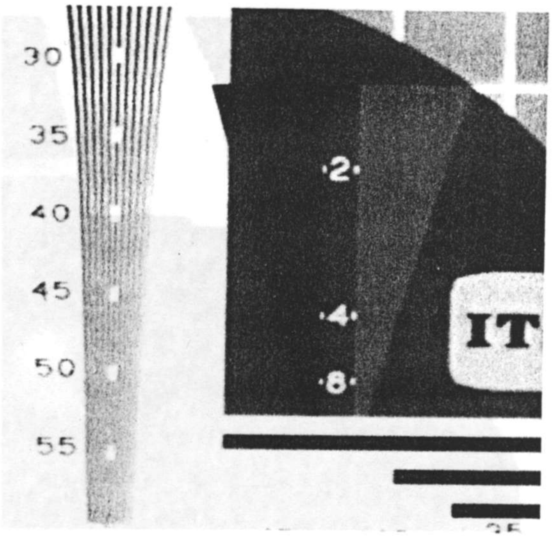
The bandwidth of the Y signal is 4.2 MHz, and those of the R–Y and B–Y signals are 1.5 MHz. The Nyquist frequency for the Y signal is 8.4 MHz; however, a clock frequency of 12.3 MHz is adopted for sampling. As a Y signal sampled at 12.3 MHz corresponds to one dot of the printer, the filtering circuit to convert the sampled dots can be neglected, simplifying the total circuit construction. There are 640 dots/line with a 12.3-MHz sampling clock for the Y signal. For the R–Y and B–Y signals, subsampling frequencies of 3.1 and 6.2 MHz, which are one-quarter and one-half of 12.3 MHz, respectively, were tested. A digital low-pass filter is not used to restore the original data from the subsampled R–Y and B–Y data because of the circuit complexity. Nearest-neighbor data are used to interpolate the R–Y and B–Y data. When the subsampling clock for the R–Y and B–Y signals is 3.1 MHz, subsampling artifacts are easily found on print samples. However, when the clock frequency for subsampling the R–Y and B–Y signals is turned up to 6.2 MHz, the artifacts are unobservable even without a low-pass filter.

Among many image compression techniques,[5] the differential pulse code modulation (DPCM) algorithm was adopted for the printer because of the following reasons.[6]

(1) For the video printer, the image compression must be done in real time (33 ms for a frame image).
(2) A lossy compression is permitted to some extent, if the human visual system does not sense the loss of image.
(3) The circuitry for DPCM is simple.



(a)



(b)

**FIGURE 2** — Comparison of compression rates.
(See color section following page 120.)

Figure 2 shows print samples for different compression rates. When all the Y, R–Y, and B–Y data are compressed to one-half, noise and jitter are found along the edges of the image, while the jitter is not noticeable when only the R–Y and B–Y data are compressed. This jitter is caused by the instability of the phase-locked-loop (PLL) circuit that generates sampling clocks, and is amplified by the data compression circuit.

In computer simulations, the DPCM algorithm gives better results than the DCT algorithm and image degradation that appears in the video printer cannot be easily seen. Different results for the same DPCM algorithm are caused by differences of the sampling clocks. The sampling clock of the video input equipment used to capture an image in the simulation is much more stable than that of the video interface in the printer. These facts mean that the DPCM algorithm must be modified for the printer, in which the stability of the sampling clock is limited.

We concluded that the best sampling frequency for the Y signal is 12.3 MHz and that for the R–Y and B–Y signals is 6.2 MHz. The Y data cannot be compressed, but the R–Y and B–Y data can be compressed to one-half without loss of image quality. The total size of image data is reduced from 1Mbyte without subsampling and compression to 500 kbytes.

| | (j -1)th column | j th column | (j+1)th column |
|---|---|---|---|
| (i -1)th line of field 1 | $f_{i-1,\,j-1}$ | $f_{i-1,\,j}$ | $f_{i-1,\,j+1}$ |
| | | | |
| i th line of field 1 | $f_{i,\,j-1}$ | $f_{i,\,j}$ | $f_{i,\,j+1}$ |
| i th line of field 2 | | x | |
| (i+1)th line of field 1 | $f_{i+1,\,j-1}$ | $f_{i+1,\,j}$ | $f_{i+1,\,j+1}$ |
| | | | |
| (i+2)th line of field 1 | $f_{i+2,\,j-1}$ | $f_{i+2,\,j}$ | $f_{i+2,\,j+1}$ |

**FIGURE 3** — Alignment of dots.

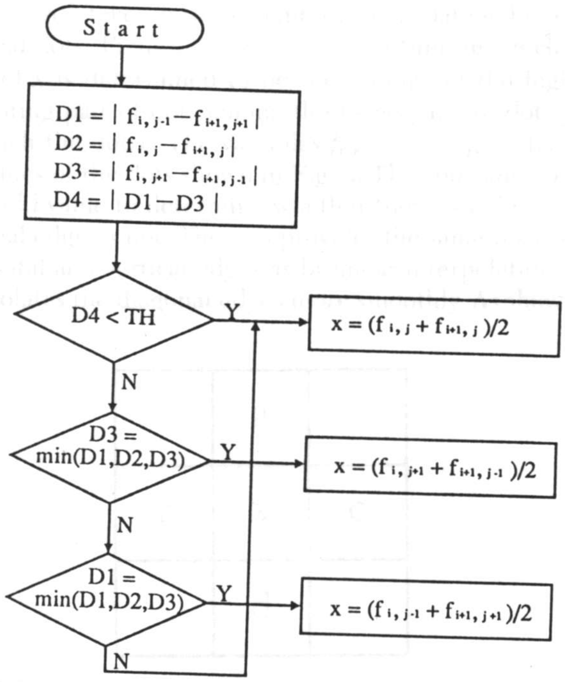
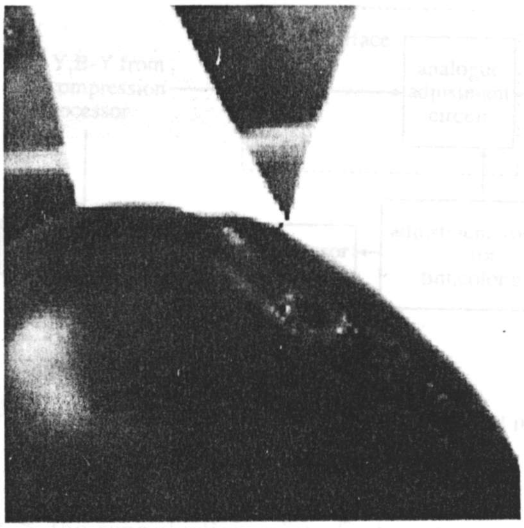
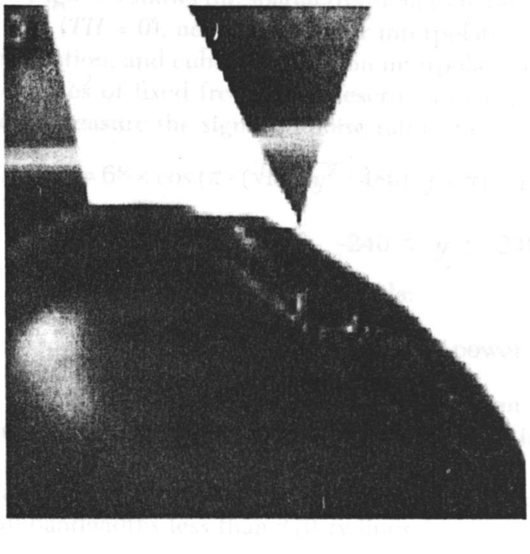



**FIGURE 4** — 3DSI algorithm.



(a)



(b)

**FIGURE 5** — Comparison of interpolation algorithms.
(See color section following page 120.)

## 3.2 Field interpolation

When a still picture is taken from moving pictures, the captured frame flickers on the monitor because each field captures a picture at a different time in the 33-ms interval. Accordingly, the hard copy produced from the frame is very degraded. One of the two fields is used to print in this case and the other field is interpolated from the selected field to make a complete frame. Figure 3 shows the dot arrangement of the two fields. The field interpolation is used to calculate the value of $x$ in Fig. 3 from the values of the surrounding dots of the other field.

Various algorithms for the field interpolation have been proposed.[7-9] Some of them achieve high image quality, but they are too complex to use within the limitations of computing time and cost for the consumer video printer. In

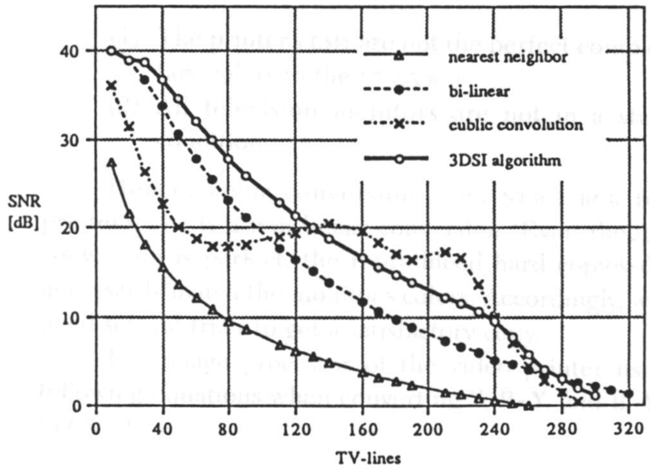



**FIGURE 6** — Spatial frequency characteristics of interpolation algorithms.

the conventional system, the value of $x$ is the same as the value of the nearest dot (nearest-neighbor interpolation), or the average of the values of the upper and lower dots (bi-linear interpolation). These algorithms are simple, but the resulting quality is also limited. We have developed a more sophisticated algorithm that is acceptable within the specific limitations for the printer. The time permitted for the interpolation ($t_{int}$) is found to be 65.1 μs/dot from the following equation:

$$t_{int} = P - \text{time} / \text{dot} - \text{no.} \qquad (2)$$

Here, $P$ - time is the real print time for each color (not including paper-feed time, etc.) and is about 10 s in this printer; dot - no is the total number of dots in a field image and 640 × 240 in the printer.

This field interpolation [3 directions selective interpolation (3DSI)] takes into account the correlation between diagonal dots. Figure 4 shows this algorithm, in which the value of $x$ is determined to be the average of the highest correlating pair of dots among the three pairs of dots that sandwich the dot $x$. The variables $f_{i,j-1}$, $f_{i,j}$, $f_{i,j+1}$, etc., are the values of the dots shown in Fig. 3. The constant $TH$ is a threshold value to determine whether there is a distinctive diagonal edge or not. The 3DSI provides the same results for horizontal and vertical edges as bi-linear interpolation, but interpolates the diagonal edges more smoothly. As shown in

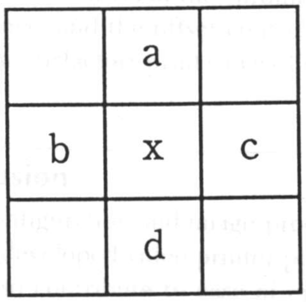



**FIGURE 7** — Dot arrangement for edge enhancement.

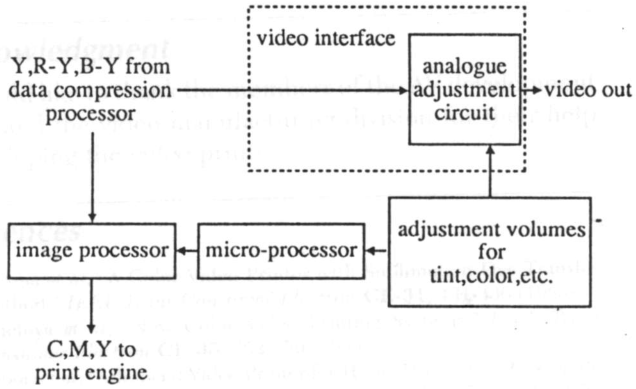



**FIGURE 8** — Block diagram of image-quality adjustment part.

Fig. 5, the reproduction print of a tomato by 3DSI is more natural than that by bi-linear interpolation.

Figure 6 shows the spatial frequency characteristics of the 3DSI ($TH = 0$), nearest-neighbor interpolation, bi-linear interpolation, and cubic convolution interpolation. Circular zone plates of fixed frequency, described in Eq. (3), were used to measure the signal-to-noise ratio (SNR).

$$Z(x, y) = 68 \times \cos\left(\pi \cdot (\sqrt{x^2 + y^2} / 480) \cdot f + \pi\right) + 138.$$

$$(-320 \leqq x \leqq 320, \ -240 \leqq y \leqq 240) \qquad (3)$$

SNR is defined by the following formula:

$$SNR = 10 \times \log_{10} \left( \sum (\text{error})^2 / \text{power} \right). \qquad (4)$$

Here, an error is the difference between the true value and the interpolated value. 3DSI is the best interpolation when there are fewer than 130 TV lines and between 250 and 270 TV lines, and better than bi-linear interpolation for all bandwidths less than 270 TV lines.

## 3.3 Edge enhancement

The printed image is sharpened by the following adaptive filter:

$$\text{factor} = \alpha \cdot (2 \cdot x - a - d) + \beta \cdot (2 \cdot x - b - c),$$

$$\text{if} ( | \text{factor} | > \text{threshold}), \ x = x + \text{factor}$$

$$\text{else}\, x = x, \qquad (5)$$

where $\alpha$ is the vertical edge-enhancement coefficient, $\beta$ is the horizontal edge-enhancement coefficient, the threshold is a constant, and the dot arrangement of $x$, $a$, $b$, $c$, and $d$ is shown in Fig. 7. This adaptive filter enhances only the distinctive edges but does not amplify low-amplitude noise components.

## 3.4 Color conversion

There are two problems for consumer video printers from the standpoint of color reproduction:

(1) The printer's CMY are not the perfect complementary colors to the NTSC's RGB.

(2) All television monitors are not in a standard condition.

Hence, color conversion from NTSC's RGB to the printer's CYM is a non-linear conversion. Even though the conversion is perfect, the reproduced hard copies do not necessarily match the monitor's colors. Accordingly, we may need several trials to get a satisfactory copy.

The image processor of the video printer uses the following equations when converting Y, R–Y, and B–Y data to CMY data:

$$C = L_1 - K_{11} \cdot Y + K_{12} \cdot (R - Y) + K_{13} \cdot (B - Y),$$

$$M = L_2 - K_{21} \cdot Y + K_{22} \cdot (R - Y) + K_{23} \cdot (B - Y), \qquad (6)$$

$$Y = L_3 - K_{31} \cdot Y + K_{32} \cdot (R - Y) + K_{33} \cdot (B - Y).$$

As long as the NTSC's primary colors are used and the printer's CMY are the perfect complementary colors of the NTSC's RGB, $L_1$, $L_2$, $L_3$, $K_{11}$, $K_{12}$, $K_{13}$, $K_{21}$, $K_{22}$, $K_{23}$, $K_{31}$, $K_{32}$, and $K_{33}$ are 255, 255, 255, 1, 1, 0, 1, –0.508, –0.186, 1, 0, 1, respectively. But these constants are slightly modified to improve the reproduction of skin tones and to increase the color saturation.

One of the important features of this video printer is that the user can easily adjust the tint, color, contrast, and luminance after capturing an image while observing the adjusted image on a television monitor. Without this feature, users would have to make repeated trials under different print conditions to obtain satisfactory reproduction.

Figure 8 shows the block diagram of this adjustment part. The output of the adjustment volumes (controls) go to both an analog adjustment circuit and a microprocessor. The analog adjustment circuit modifies the image on a television monitor. When printing, the microprocessor reads the positions of the controls through its analog-to-digital (A/D) ports and sets the $L_i$'s and $K_{ij}$'s to the appropriate values. The tint adjustment, color adjustment, contrast adjustment, and luminance adjustment correspond to the rotation of the chrominance, gain control of the chrominance, gain control of the luminance, and the offset control of the luminance, respectively. A satisfactory print can easily be obtained using this feature.

## 4 Conclusion

The system configuration and image-processing techniques for the newly developed video printer produce good image quality and also contribute to ease of operation and compactness of equipment. These features will enlarge the market for consumer video printers.

## Acknowledgment

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