Digital Image Processing for the Frontier350 Digital Minilab

Hiroaki Nakamura
Fuji Photo Film Co.,Ltd
Ashigarakami-gun,Kanagawa,Japan

Abstract

The Frontier 350 is a multifunction, high-image-quality Minilab system capable of printing not only from negative and reversal films but also from various digital sources that include digital cameras.

Its image processing capabilities include color and density adjustment processing, automatic dodging ("Hyper Tone"), granularity-suppressing sharpness enhancement ("Hyper Sharpness"), lens compensation, and red-eye correction.

Most image processing functions are implemented in the form of application-specific ICs (ASICs) or are run at high speed by a high-performance microprocessing unit (MPU); thus, high-quality prints can be obtained without eroding printing productivity.

Color and density adjustment processing controls the imaging of the principal subject so that it is finished at the appropriate density. To achieve this, we developed our own auto-setup algorithm that utilizes face-density information. This algorithm significantly raises the probability that the produced prints will be accepted above what it is with the conventional lab systems.

Introduction

In 1996, we introduced Frontier, the world's first fully digital lab system. Frontier was equipped with epoch-making image-processing technologies, such as automatic dodging, enhanced sharpness with minimal film granularity, and contrast correction for underexposed negatives.[1]

For its successor, Frontier 350, not only did we expand the range of multifunctional features to include lens compensation and red-eye correction, but we focused our research and development on enhancing productivity so that this model, the latest, can supplant the conventional Minilab systems.

Herein I provide an overview of the image-processing capabilities incorporated in Frontier 350. I explain the face-extraction algorithm by focusing on the technology for extracting the subject's face - technology used for the first time ever. This is followed by an explanation of how application of this algorithm to automated density adjustment processing significantly boosts the yield of acceptable prints compared with the conventional lab equipment.

Frontier 350 Digital Minilab System

System Overview

Frontier 350 consists of two units: an input unit that incorporates an input scanner, image processor and controller and an output unit that accommodates a laser printer and paper processor. A high-speed serial interface connects the units. The system can be expanded by connecting a personal computer through a network (Fig. 1).

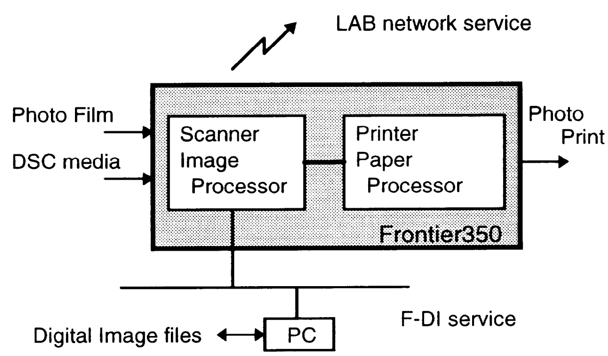

Figure 1. Frontier 350 digital minilab

Table 1 shows major specifications. Photographic film is read with a line-type CCD that captures red, green and blue (RGB) color information separately at a resolution of 5,000 pixels per primary color. The image processor with integrated scanner processes in real time the signals derived from the CCD.

Images are output to silver-halide color paper using a trio of RGB lasers. Output resolution is 300dpi.

Our company, Fuji Photo Film, developed the high dynamic range three-line CCD and solid-state lasers (for blue and green) using its own technologies.

Table 1. Main Specifications

Feature	Specification
Image input scanner	RGB 3-line CCD
Image processing	Custom ASICs
Image exposure scanner	RGB lasers
Productivity	135-3R: Approx.1,300prints/hr. 135-4R: Approx.1,050prints/hr.
Print sizes	82.5x117 - 254x384mm
Printable image sources	Negative film, Reversal film, Digital still cameras

Image Processing

The image processing technologies incorporated in Frontier 350 can be roughly divided into four categories.

The first category is technology to guarantee fundamental image quality: optimal design of tone reproduction curves and three-dimensional lookup tables (3D-LUTs), which determine both color reproduction and imaging characteristics, such as image granularity and sharpness.

The second category consists of Auto-Setup technology: automatic calculation of the best possible reproduction conditions based on a variety of shooting conditions and the type of film used. Auto Setup's primary role is to derive the adjustment value with which to determine image gray balance and reproduction

density. In the Digital Lab System, Auto Setup also derives the optimal contrast and sharpness parameters.

The third category represents image-quality enhancing technology and special effects, such as red-eye correction (elimination), soft focusing and lens correction. These types of processing have only been made possible by the use of the technologies present in our Digital Lab System. To impart added value to images, we are considering continued expansion of the range of functionality.

The fourth category is comprised of editing technology, or "Variety Prints." It consists of the layout/template photomontage technology for creating calendar prints, greeting cards, framed prints, and the like.

Almost all image processing, excluding image editing, is performed in real time using the exclusive hardware. Auto-Setup computations are made by the general-purpose MPU incorporated in the controller.

Frontier 350 is the product of diverse functional improvements. The Auto-Setup technology, for one, is a crucial feature that sets the Frontier 350 apart from the conventional lab systems.

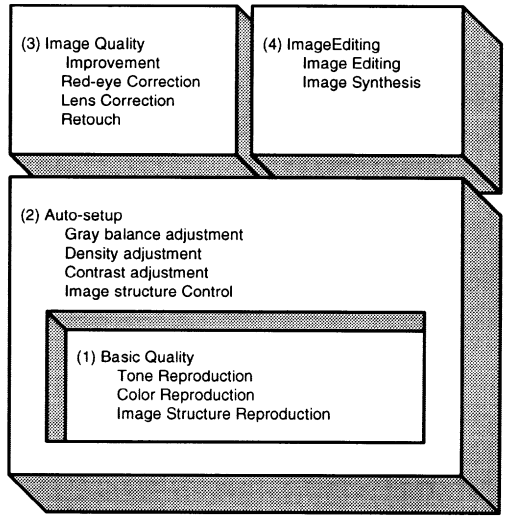

Figure 2. Frontier 350 image processing

Auto Setup

Auto Setup Feature

Face-extraction technology for density adjustment is the salient feature of Frontier 350's Auto Setup.

The idea of using density information read off an image captured on film to control exposure when printing photographs has long been proposed. Research on methods for using skin-tone-area information has been conducted since the 70's. Moreover, since the second half of the 80's, other companies have been attempting automatic face extraction of on-film figures through recognition technology.

During that time, we obtained results that indicated that the rate of print acceptability could be significantly increased by applying facial-complexion information to density adjustment. However, with the conventional analog Minilab systems, it was extremely difficult to incorporate this approach, owing to the constraints of the hardware resources available then: the limited resolution of input scanners and insufficient numerical operation performance.

Since Frontier 350 is a digital Minilab system, it is equipped with a high-performance scanner and high-powered MPU, which have made it possible to incorporate our density-adjustment technology that is based on face extraction.

Figure 3 illustrates the step-by-step progression through the Auto Setup sequence.

First, the image's gray-balance adjustment is computed. Next, the value of density adjustment is determined based on the density of the area of principal concern and the quantity of features in other image areas.

In a frame that contains a subject (person), the density of the face represents the density of the principal area.

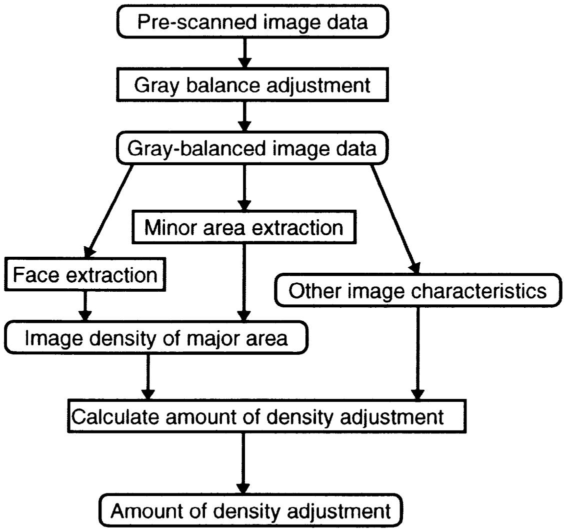

Figure 3. Auto setup

Relationship between facial density and density adjustment performance We gleaned the following results from our market research.

(1) In the scenes generally captured on film, the face constitutes the principal part about 75% of the time.
(2) Around 90% of rejected frames had faces on them that constituted the principal part.
(3) Rejection was attributed to failed density reproduction about 90% of the time.

Thus, if facial information can be accurately extracted and applied to density adjustment, it may be possible to significantly raise the print acceptability rate.

Assuming that it is possible to extract the face perfectly 100% of the time, we made simulations to determine the extent to which the success rate can be actually improved. Results are shown in Table 2. The subjects captured on all 2616 frames that were used in the experiment were people. The value of density adjustment was obtained using linear regression on LATD control results, with the differential between facial density and average image density serving as the characteristic value. The correlation coefficient between density characteristics and corrected target values was extremely high: 0.94. The results of the simulation revealed that implementing density adjustment with simple linear regression alone is sufficient for raising the print acceptability rate to at least 98%. Face extraction technology plays a crucial role in determining the reproduction density for photographic prints.

Table 2. Effect of density adjustment based on facial density

Scene	Frame count	Correlation coefficient	Passing rate (%)
Flash(1)	752	0.943	98.1
Day light(2)	1864	0.927	98.4
(1) + (2)	2616	0.943	98.1

Face Extraction Algorithm

It is an extremely difficult challenge to extract with a high degree of accuracy faces from photographic images of varied scenes. However, the wide margin of extraction error makes for a very high possibility of practical application, as long as face extraction is adapted to the narrowly defined application of density adjustment.

The following three research and development themes must be addressed in developing face-extraction algorithms for incorporation into lab systems:

(1) achieving high face-extraction performance,
(2) ensuring high repeatability and
(3) making the computation cost low.

To satisfy these conditions, we developed a method in which broad-brush extraction is done based on skin-tone information, after which the facial area is closely defined.

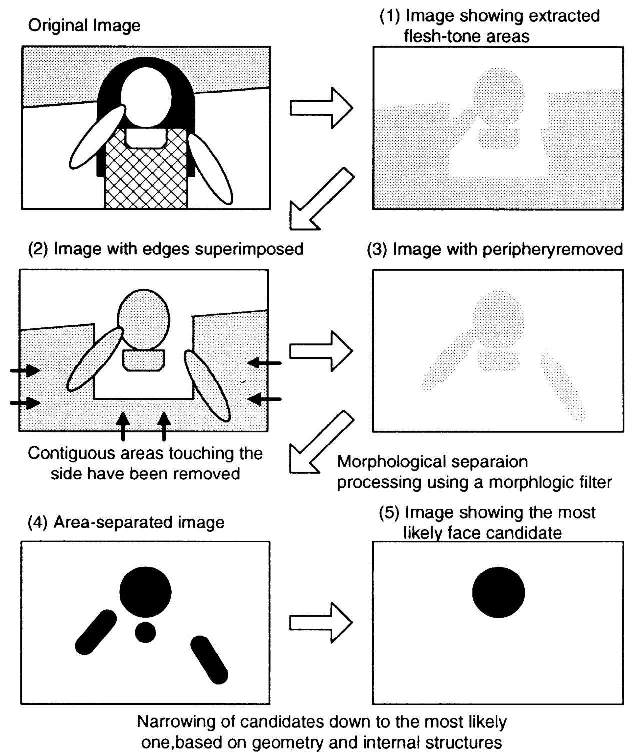

Figure 4. Extracting possible faces using color and shape

Figure 4 illustrates the method by which face-candidate extraction is done based on skin color and shape information. Flesh-colored areas are extracted from the image, which has undergone gray-balance adjustment. Due to variations in shooting conditions and in the complexions of people themselves, the range of flesh tones to be extracted is set fairly wide. To separate the face and other portions from the flesh-colored areas extracted, area separation processing is done with the help of a morphologic filter. The shapes of the individual separated areas are checked in order to extract possible face-candidate areas.

Facial contour information is used to single the face out from candidate areas. Outlines are obtained through edge tracing based on images of variable density.

Optimized algorithms have made it possible to cut the computation time required to extract a face area to less than 100 msec. per frame using a 266-MHz Pentium II[R]personal computer. (Pentium is a registered trademark of Intel Corporation.)

Figure 5 indicates face-extraction performance. The graph exhibits the relationships among threshold values, the face extraction ratio and the correct face ratio. The face extraction ratio and the correct face ratio are defined as follows:

Extraction ratio = Number of correct faces extracted / Total number of faces (1)

Correct face ratio = Number of correct faces extracted / Total number of faces extracted (2)

A total of 2,616 frames containing faces were used for evaluation. Image size was 248 x 164 pixels. As Frontier 350 uses a smaller image size, actual extraction performance is considered to be somewhat lower than Figure 5 shows.

The correct face ratio rises with stringency in face selection, lowering the face extraction rate in turn. This relationship makes it difficult to determine optimal face-selection threshold values.

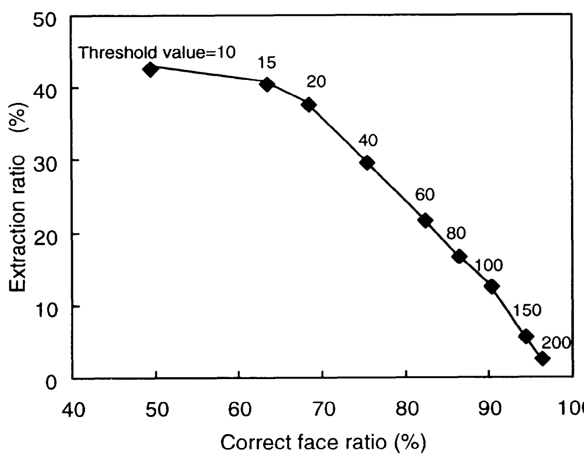

Figure 5 Performance of face extraction

With Frontier 350, threshold values are not used in face selection. Instead, a method has been adopted to ensure reliability by digitizing (converting to numerical form) individual face-candidate areas based on contour information. The reliability enhances the contribution that facial density adjustment makes.

Acceptable Print Yield Evaluation Results

Figure 6 shows the results of density adjustment performance evaluation using the new face extraction technology that we developed.

For comparison, the performance of our conventional Minilab system has also been presented. The horizontal axis represents the deviation from the target density adjustment value. The unit is color paper density. 3,200 frames were used for optimization and another 1,100 frames were used for evaluation.

As can be seen, in terms of density adjustment error, the number of frames with less than 0.25(D) and the number with less than 0.35(D) increased about 6% and 4%, respectively, as compared with our conventional Minilab systems. These figures indicate a significant rise in density adjustment performance.

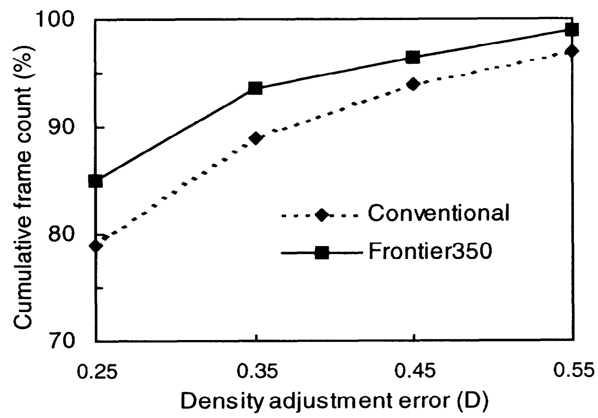

Figure 6. Evaluation results of density adjustment

The results of evaluation of prints (produced automatically by the Frontier 350) using our company's pass/fail judgment criteria confirmed an increase of over 4% in the print "pass" rate as compared with our conventional Minilab systems.

Conclusion

(1) We developed Frontier 350, a fully digital Minilab system.

(2) Frontier 350 is equipped with new capabilities possible only with a digital lab system: Hyper Tone, Hyper Sharpness, lens correction and red-eye correction.
Most of the image processing can be done in real time without deteriorating printing productivity.

(3) Incorporating our face extraction technology in Frontier 350 has made it possible to improve the print "pass" rate at least 4%, automatically facilitating the generation of high-quality prints.

References

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