

Image Quality of Digital Photography Prints—2: Dependence of Print Quality on Pixel Number of Input Camera

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Abstract

In the digital photography, the input photo-image is sampled by segmental imager and then converted into the electronic signal. The divided unit of imager is called a pixel and the segmentation fixes the size and number of pixels. The definition of output pictures is directly related to the pixel number of the input imager. Thus it is a key function for image quality of the output picture in digital photography.

This paper discussed the relation between pixel numbers of imager in the input digital cameras and image quality of output prints. The sample prints showing the same pattern images in the different definition proportional to the pixel numbers of imager were produced by digital photography system. The image quality of those sample prints were evaluated by subjective human viewings and objective image structural analyses.

The correlation between pixel numbers consisting of prints and their structural image quality was distinctive on the subjective visual and the objective physical evaluations. The results suggested that the optimum pixel numbers of imager in digital cameras to produce hand-held size digital photography color prints.

Introduction

In the digital photography system, the definitions of input capturing devices and output printing equipment, the quality of printing media and display devices are key factors to determine the image quality of the output images. The input photo-electronic converting device in the digital camera is called an imager. The definition of it counted by pixel number is the most effective function to the image quality of output prints.

Preparation of Sample Prints

The sample images for evaluations were a female model and resolution charts printed on the various kinds of digital prints. Those sample prints were simulation pictures produced by following procedures; 1) the objects were taken by digital camera under the optimum illumination to overcome the narrow dynamic range of camera imager, 2) image data processing was done by computer manipulation to crop and to interpolate pixels, and 3) processed image data were supplied to the three kinds of printers having different printing conditions. Thus the sample prints were simulation images and have the same patterns in the different image structures.

The principle of data flow in the image processing was as follows: 1) the input data for the processing were fixed to be 5.24 million pixels and R,G and B color data level of 10 bits, the individual pixels carried segmented image information, 2) the manipulation procedures was the selection of pixels carrying specific information and the quantitative compensation and data compression of pixels to recover to the original number of 5.24 million and to convert R, G and B data level of 8 bits for the convenience of printing. After the processing, the size of pixel carrying the original information was modified. According to this process, the same size sample images showing the same content in the different pixel condition were synthesized. This process corresponds to the enlargements of photographic images on the different size negative film to the uniform size prints.

The digital camera using in this work was Sony's studio camera, DKC-ST5 having three 2/3 inch class 1.4 million pixel CCD, charge coupled device imagers arranged by spatial offset method. The actual imager size was 8.7 mm x 10.0 mm. The spatial offset is a virtual method to increase the effective pixel numbers of imagers made by geometrical arrangement of individual imagers.[1] The pixel number of individual CCD was 1.31 million (1024 x 1280) and the number of combined imagers after the interpolation were equivalent to be 5.24 million (2048 × 2560). The visual resolution of camera output evaluated by chart pattern printed on a print was 1500 lines per picture height. The camera lens was a zoom-type one tunable its focusing distance from 12.5 mm to 63 mm. These focusing distances were equivalent to be 50 mm to 250 mm for 35 mm film camera. This camera had a buffer memory devices to save the data of nine shots and then quick interval shooting was available. The output data level of R,G, and B, color signals from the camera were ten bits.

The picture shooting was done under the illumination of electronic flash (strobo light), the objects were female models, ISO resolution chart for digital camera[2] and EIAJ's; Electronic Industry Association of Japan "sin density" modulation transfer function: MTF chart for video cameras. The five shootings of object in the same pose taken by changing of focusing distances were done during scores of seconds.

The image processing for the output data from the digital camera was proceeded by Macintosh personal computer using Adobe's Photoshop Ver.3J software. Figure 1 shows the procedures of image processing. The manipulation procedures were a cropping of the specific patterns from the original images and an interpolation to grow up pixel size for printing. The cropping was to extract the fixed patterns in serial images taken by different focusing distance of camera lens. As the result, five different size pictures showing the same pattern were formed. The sizes and numbers of pixel for the cropped images showed a distinct relation. The non-cropped biggest image had the larger number of pixel, however the cropped images were formed by smaller numbers of pixels. The interpolation was the increase of pixel number to the fixed 5.31 million for the printing. In the cropped pictures, the pixel was grown up by interpolation of same level pixel. It looked like a bundle of original pixels and the larger size pixel showing the same data level was formed. This method is named the simple interpolation and noted the nearest neighbor interpolation in the Photoshop software.

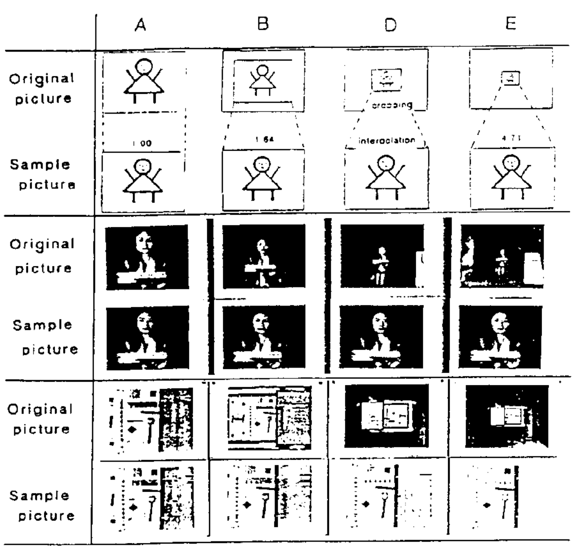

Figure 1. Procedures for sample print making

In the experiment, the first step of computer manipulation was the coding to crop the object image pictures shot by different focusing distances. The cropping, an extraction of specific part from the original picture was normalized by object of resolution chart. The sizes of chart image on the original pictures were decreased by shorter focusing distances on the camera's zoom lens. The cropping out of the chart images was normalized by picture height of it. On the original picture taken by focusing distance of 63 mm, the full frame of picture filled with chart patter was formed and it was consisted of 2048 pixels for vertical direction. Under the shooting by shorter focusing distances, the size of chart image became smaller and the vertical pixel number was decreased. The vertical pixel numbers in the cropped pictures decreased from 2048 to 1310, 942, 594 and 435 for the focusing distances of 40, 30, 20 and 12.3 mm, respectively. The area cropping ratios of them were 0.40, 0.23, 0.10 and 0.04, respectively. According to this process, the pictures showing the same poses of lady in the different sizes were cut down.

In the next stage was the decoding of interpolation and the vertical pixel numbers in the four cropped pictures were increased to the fixed 2048. The individual pixel in the cropped picture was multiplied and bundled up. As the result, bigger size pixel showing the same data level were formed. The bundle ratio corresponded to be inverse proportional to the cropping ratio. Thus the image data of five original pictures supplied to the printer consisted the same pixel numbers of 2048 × 2560, however output prints from the printers were contained the different information density. In the same size pictures, the non-cropped sample print contained the full information supplied by over five million pixels and that of the extracted print as the cropping ratio of 0.04, the print E, contained about 0.3 million pixels including individual image data. During the processing, the R,G and B color data level of 10 bits reduced to 8 bits each.

As the result, the pixels of five images after processing were unified to be 2048 × 2560 for printing. The pixel size of the sample E formed by highest interpolation ratio was 25 times bigger than that of sample A remaining the original status. This process corresponds to the enlargements of photographic images on the different size negative film to the same size photographic papers.

The reproduction of manipulated image data were done using three digital printers showing the different printing conditions. The first, "large" format prints were made by thermal dye transfer printer of Sony UPD 8800 showing the printing density of 300 DPI (dot per inch). The reproductions having 2048 × 2560 pixels were printed as the size of 173 mm × 214 mm. The second, "medium" format prints were made by therm-developable silver halide color printer of Fuji Film's Pictrography 2,000 showing the printing resolution of 400 DPI and picture size was 130 mm × 161 mm. The last "small" format prints were printed by negative-positive type trial laser photo-printer made by Fuji Photo Film Co.. The printing density was 500 DPI and the print size of the outputs were 103 mm x 128 mm. As the result, the three different size sample prints were formed. The equivalent pixel sizes of prints produced by manipulation were changed from 84 μm square to 400 μm square, 63 μm square to 300 μm square and 50μm square to

239 µm square for the "large", "medium" and "small" format prints, respectively.

Examinations

The subjective evaluation was the viewing of sample prints on the table in office room under the illumination of fluorescent lamps in 1200 lx. The five samples printed by data consisting of vertical pixels of 2048, 1310, 942, 594 and 435 were numbered A, B, C, D and E, respectively. The three size samples were named "large", "medium" and "small" Format prints, respectively. The viewers watched A to E samples being in a line under the well viewing distance of about 300 mm. That distance was supposed to be equivalent with the hand-held distance.

The evaluation was to count the subjective quality of image definition in four grades of point 3 for "excellent", point 2 for "fair", point 1for "poor" and point 0 for "unacceptable". The viewers were two groups of a 38 students in photography course in art school and a 17 engineers designing digital cameras.

The objective evaluations were measurements of density changes and microstructures of chart images on the sample prints. The density changes were measured on the stair charts pattern on the sample prints of female model. The measuring equipment was "Exlite reflective densitometer". The neutral reflection density was measured under the aperture of 2 mmΦ. The microstructures of images measured on the sin density MTF charts on the samples by microdensitometer, Konica PDM2405 in reflection mode.

The apertures of equipment were 50µm (width) x 100µm (height).

Results of Evaluations

Table 1 shows the cropping conditions, visual resolutions and the pixel sizes on the processed sample prints. The vertical pixel numbers of cropped images spread from 2048 to 435 and these numbers corresponded to be twice scanning lines of high definition TV picture to the current VGA; video graphic array level pictures. The visual resolution of ISO chart of five samples were from over 1500 lines to 333 lines per picture height.

Table 1. Conditions for sample prints producing.

Print Number	Original pictures			Sample prints (large format, 300DPI, 173 x 216 mm)			
	Shooting & processing			Effective pixel			Limiting Resolution (lines per picture height)
	Focusing Length (mm)	Pixel number (million)	Cropping ratio (%)	Interpolation ratio (%)	Pixel number (million)	Pixel size (µm sq.)	
A	63		100	—	5.20	84	1500
B	40		64	164	1.82	138	800
C	30	5.20	46	226	1.09	183	550
D	20		29	307	0.60	290	350
E	12.5		21	408	0.25	400	250

Generally on the electronic cameras, the limiting resolution was experimentally supposed to be 70% of the numbers of vertical pixels or scanning lines.[3] In this work, the individual visual resolutions indicated to be 57 to 72 % of equivalent vertical pixel numbers. It will be reasonable that the five sample prints of A to E were reproductions shot by digital cameras having the imagers of vertical pixel numbers of 360 to 2000 classes.

Subjective Evaluations

The visual evaluation of sample prints showing one female model was evaluated by two groups of observers. The examination was a kind of psychological evaluation to identify the image quality of sample prints as photographic grade. This examination was so called a category evaluation.[4] The concept of this method was to compare with the quality levels of cabinet size traditional color photographic prints made by printing of 35 mm color negative film image to positive color paper as a reference and the sample prints.

On the evaluation, the question was the subjective allowance of structural image quality as level of photographic prints. The concept of photography prints will recognize the pictures as the following terms; smooth continuous tone rendition and plentiful color reproduction, fine and smooth expressions of shot images, comfortable feeling of print itself, durability and permanence. In this work the evaluation terms were limited of the fine and smooth expression of image. The judgment was the definition of sample prints of A to E. If the quality of sample print was supposed to be the same level as the regular photographic color prints, to mark it as "excellent" and to vote point 3. The next level print marked "fair" for point 2. Following that the markings were "poor" for point 1 and "unacceptable" for point 0.

Figure 2 shows the relation of pixel numbers of sample prints and the subjective evaluation values by observers. The evaluation values of the vertical axes were the average of voting points. In general, the evaluation values rose smoothly according to the increase of pixel number. In the cases of medium and small format prints, the values were nearly saturated over the pixel number of over 2 million.

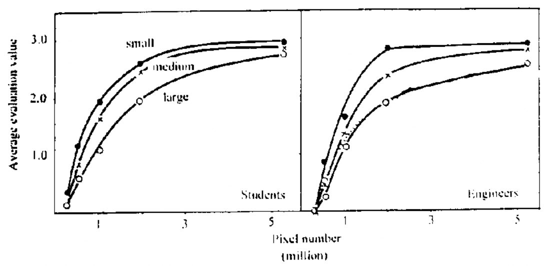

Figure 2. Subjective evaluation of sample prints – 1 (average evaluation values)

In the case of evaluation by students in photography school, sample prints consisting of over five million pixels, the average marks for three format prints are closed to mark 3.0. Generally the increase of average voting marks are evenly. In the cases of sample prints C, D, and E having pixel number less than two million, the results of the medium and small format prints are nearly the same. That of the large format prints, the average marks are markedly decreased. On the contrary, the evaluation by engineers shows little different results. The increase of evaluation values are steep near the pixel number of two million.

Figure 3 shows the relation of the voting ratio of "excellent" and pixel number of sample prints evaluated by both groups. The voting ratio of 100 % means the all members of 17 or 38 evaluated the sample as "excellent". In any sizes, the voting ratios was very high only in the case of sample print A. There was no "excellent" voting for the prints having less than one million pixels of sample C, D and E. The distinct difference between the students and engineers is appeared in the sample print B. The voting ratio was the nearly same as that of five million.

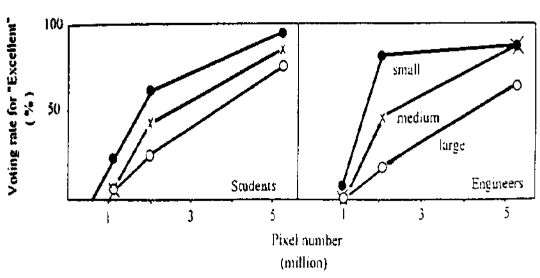

Figure 3. Subjective evaluation of sample prints. (Voting rate for "excellent")

Objective Evaluations

The objective examinations were the densitometric analysis measuring the density step chart holding by female model and the microdensitometric analysis to measure the sin density patterns for MTF chart image on the sample prints. The results of densitometric measurement showed indistinct effect of interpolation on the density curves. There was only indistinct effect of interpolation inducing the digit density change by bundle of unit pixels. The only change was the slope of density curves; gamma, the smaller format prints show the steeper gammas. It may be depend on the relation of aperture size of densitometer and pixel size.

Figure 4 shows the MTF characteristics of three format sample prints. On the measurements, the aperture width of the microdensitometer was 50µm and equivalent to the smallest pixel in the "small" format sample prints. On the direct viewing of hardcopy prints, the comparative resolution of human eye having the sight of 1.0 is supposed to be 80µm[5] and that of 50µm is the value including the prolixity of above resolution.[6] In the Figure 4, the spatial frequency values are converted to the style of photography; lines/mm for the simple discussion for the direct viewing hardcopy prints.

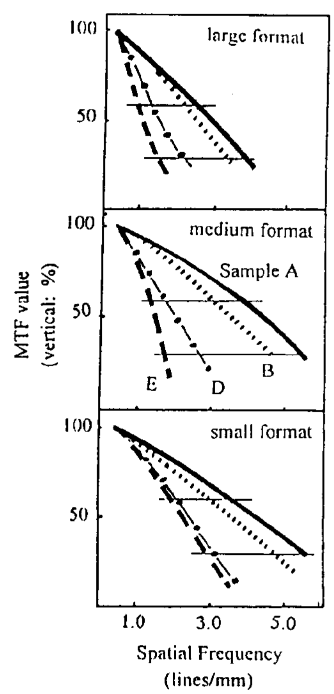

Figure 4. MTF Characteristics of sample prints.

The MTF curves of three format sample prints show the different trends because these were produced by different printers. Thus the detailed discussion is limited of the same format prints prepared by serial processing. In every sample prints, the bulge of curves are shrieked by interpolation. In the any format prints, the MTF curves for A had gentle slope and tailed to the high spatial frequency regions. Those of print E were very steep and fell in the low frequency region. Those of B showed very closed trend with A, however those of D closed to E. There were big difference between MTF curves for B and D prints.

The typical MTF characteristics was apparent in the changes of spatial frequencies at MTF value of 30 and 60%. Table 2 shows the spatial frequencies of the MTF values at 30 and 60% for four sample prints in three formats. In general, the frequency changes were more distinct in the smaller format sample print that those of the large format ones. At the both MTF values, frequencies changes between sample A and B, D and E were not so narrow range, although those of B and D were great. These trends were more apparent in the case of frequencies at MTF at 60%.

Table 2. Spatial frequencies for MTF values at 30 and 60%

MTF value (%)	Print format	Spatial Frequencies (lines/mm)			
		Print A	Print B	Print D	Print E
30	Large	2.40	2.10	1.25	1.50
	Medium	3.80	3.10	1.70	1.40
	Small	3.70	3.00	2.20	1.90
60	Large	3.95	3.40	2.10	1.50
	Medium	5.90	4.70	2.90	1.80
	Small	5.75	4.80	3.25	2.95

Line mm on verticle direction, aperture size 50(H) x 100 (V) μm2

Summary

The conditions of photographic color prints to satisfy regular customers are too numerous to mention. In the case of the traditional photography prints, so-called analog prints are inherent in the excellent characteristics of media itself, photographic equipment and the long efforts made by people in the industries and users.

In the case of digital photography prints, there is big structural problems caused by arrangement of digit pixels. We dislike to recognize the notched image structure of prints made by pixels. We must visually eliminate it and attain to be it like the current analog photography. We have to find out the optimum conditions for the advance of digital photography.

This work was based on above concept and aimed to find out the optimum image structure to recognize the digital prints as the current color photographic prints. The easiest way is to consist of the image structure using the small components of pixels to overcome the resolution of the human vision. In this work, the correlation between the structural quality and pixel number of the digital prints was clarified. The discussion of such correlation using temporary digital prints produced by segmented traditional color photographic prints was tried.[6] In that work, the preparation of unified size sample prints having the same image in the different pixel condition was not so easy. Thus the systematic discussion was not completed. In this work the discussion was evolved using real digital prints having wide ranging pixel condition in different format prints.

The results of subjective evaluation showed in Figure 2 and Figure 3, one suggestions is considerable; it is that if the acceptable quality level of sample print was the marked to be 3.0 as the "excellent" level, the pixel number of print must be over two million. If it expand to the level of the "fair", the range of pixel number will spread to be over one million.

The print sizes spread from 173mm x 210 mm to 103mm x 128mm. However, the effect of print size was not so distinctive because these were all hand-held size and viewing condition was nearly the same. The one attention was that the evaluation points for the large format marked lower than the others. As the result, the sample prints of A and B consisting of five million and near two million pixel were subjectively evaluated as the same level as the current photographic prints.

The results of objective evaluation showed on Figure 4 and Table 2, the subjectively acceptable prints showed the MTF characteristics to spread to high frequency range. There were big difference of the spatial frequencies between the MTF values at 60 % in the sample prints of B and D, consisting of pixels of two million and half million, respectively. These difference depended on the fact that the objective evaluation reflected to the above subjective difference. On the visual frequency response, such frequency shortage is very effective to the comfortable viewing of prints.

The results of this work limited the case of image of a bust shot, although it was supposed to be concluded that the use of digital camera having imager(s) of near two million pixels can generate the sufficient image data to produce hand-held size digital prints satisfying the customer's demand in the structural image quality.

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