2,540 dpi Full Color Image Creation with a Liquid Electrophotography System

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Abstract

Extremely high-resolution images have been obtained by an electrophotographic imaging system using liquid toner. This system includes a high-resolution Laser Scanning Unit (LSU) with a 2,540 dpi resolution, and an image transfer system that does not use electrical energy. We examined the characteristics of high-resolution image creation, in particular the relationship with laser beam focusing and laser power to obtain the optimized parameter value of the LSU. The image pattern from this system was confirmed to be accurate according to the resolution. Furthermore, an examination of the noiseless transferability of "shearing transfer" showed the accuracy of the created image was due not only to the development process, but also to the transfer process. We attempted to print a full-color image with this system, and obtained a real 2,540 dpi color image, which is equal in quality to that produced by offset printing.

Introduction

One of objectives of electrophotography is to realize a high-quality image equal to produced by offset printing.[1] The increase of resolution has an important bearing on the improvement of image quality.

In electrophotography using dry toners, various approaches have been employed in order to realize high-resolution images, for example development of toners with smaller particle size, and high-resolution exposure. However, the resolution is limited to 1,200 dpi because of a toner particle size limitation (>5 micrometers) and a toner scattering problem.

Meanwhile, electrophotography using liquid toners is expected to overcome the limitation. The image pattern created by the liquid electrophotography was confirmed to be accurate according to the source image pattern without any noise in our study.[2,3] Advantages of liquid electrophotography are mainly due to small-size toners (<1 micrometer), but in addition we developed other technologies for high quality.

In this paper, we show that high-resolution images of 2,540 dpi are obtained with the liquid electrophotography system we developed, which are comparable in quality to those produced by offset printing. Furthermore, we reveal that high-resolution laser exposing technology and high-accuracy transfer technique contribute to the high-quality imaging.

Composition and Process of Liquid Electrophotography System

Figure 1 shows the configuration of the liquid electrophotography system. The system includes a photoconductive drum, and a scorotron charger, LSU (a laser scanning unit), a development unit, a squeezing unit, a dryer, and a transfer unit at the periphery of the photoconductive drum. The LSU has a resolution of 2,540 dpi. The development unit accommodates four developing devices containing liquid developers of different colors, namely yellow, magenta, cyan, and black respectively, and slides every revolution of the photoconductive drum.

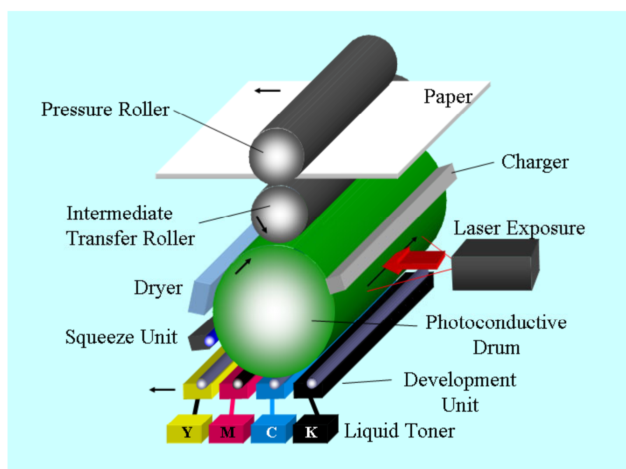


Figure 1. Configuration of the liquid electrophotography system

This system employs the Image-On-Image (IOI) color process. After the forming of the first color image on the photoconductive drum, the second color image is superimposed on the first color image. The third and fourth images are formed in the same manner. The full color toner image on the photoconductive drum is dried properly by the dryer removing the solvent content, and transferred on a paper via intermediate roller without electrostatics.[4] An image transfer is conducted by a "shearing transfer method[5)]" which provides high transfer efficiency.

Techniques for High-Resolution Imaging

One of the advantages of liquid electrophotography is high-resolution power due to small particle size toners. In addition, our system includes a high-resolution LSU and a highly accurate transferring process. We optimized the optical property of the laser beam to obtain high-sharpness images. Furthermore, we confirmed that our transfer process contributes to high-quality imaging.

2,540 dpi Laser Scanning Unit

Table 1 shows the specifications of the LSU (developed by OPCell Co., Ltd.) with which our system is equipped. The beam spot is about 17 micrometers ($1/e^2$) and enables the formation of dots at intervals of 10 micrometers (2,540 dpi).

Table 1. Specifications of LSU

Resolution	2,540 dpi
Spot size	17 micrometers
Laser source	Semiconductor
Wavelength	650nm
Process speed	26.67mm/sec

Characteristics of High-Resolution Laser Beam

First, a laser beam profile is calculated to estimate a resolving power by the equation[6]

$$I(x,y) = \frac{2P_0}{\pi\omega_x\omega_y}\exp\left\{-\frac{2(x-vt)^2}{\omega_x^2} - \frac{y^2}{\omega_y^2}\right\} \quad (1)$$

where I(x,y) is a beam power density at location (x,y). P_0 is a beam power and ω_x, ω_y are the radius of beam spot. v and t are a scanning velocity and time, respectively. After the calculation of a power density as a single beam profile by equation (1), other beam profiles according to an image pattern were determined using the single profile. Figure 3 shows the power density distribution with various focus positions (from -0.5mm to +0.5mm), when LSU exposes at intervals of two dots (Figure 2). Power density was regulated by the maximum value. The status of beam separation was changed with focus position. The MTF of beam profiles provided the maximum value at focus position=-0.25mm. Meanwhile the maximum power density peaked at focus position=+0.25mm. We defined the product of MTF and the maximum power density as the resolution index of laser beam R, which shows the maximum value at focus position=0.

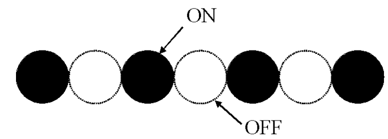


Figure 2. 1 on-1 off image pattern

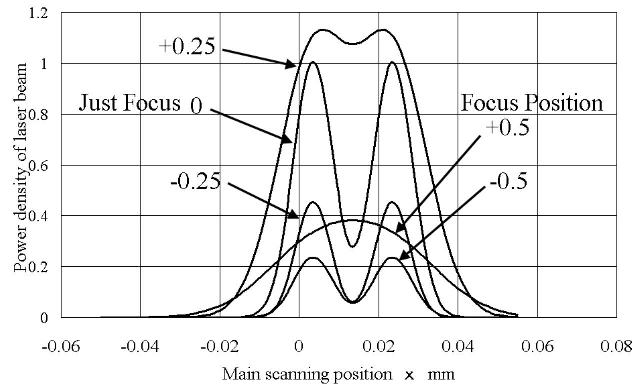


Figure 3. Laser beam profiles according to focus positions

Next, the dots formed on a paper at intervals of two dots were analyzed. The dots were formed by the laser beam with various focus positions. They were input into a personal computer as digital data of brightness by a stereoscopic microscope and a CCD camera. Figure 4 shows a distribution of the brightness.

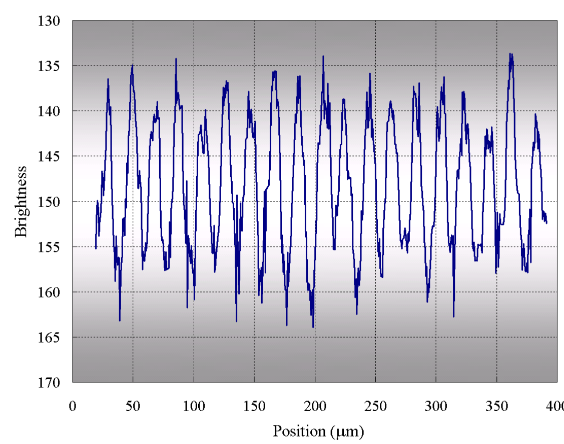


Figure 4. A distribution of brightness

The standard deviation of the brightness values was defined as the sharpness index of image S. If the dots are well separated, S will be higher. The S value at various focus positions showed the maximum at focus position=0.

Figure 5 shows the relationship between the index S and index R. A positive correlation was confirmed to exist.

The above results indicate that the best conditions of a laser beam to obtain the dots of 2,540 dpi are determined with the sharpness of a beam profile and the power density. The dots were formed accurately according to the source image pattern in Figure 6 with the laser beam of just focus.

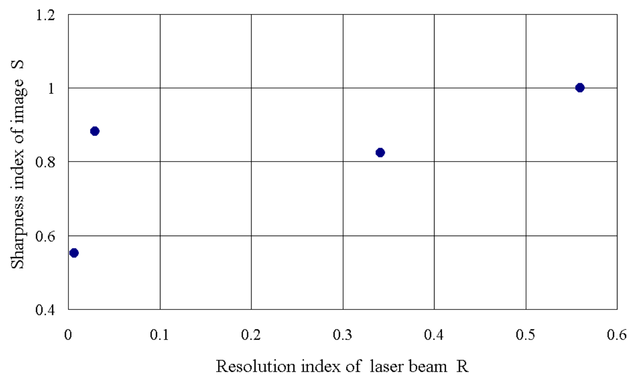


Figure 5. The S-R characteristic

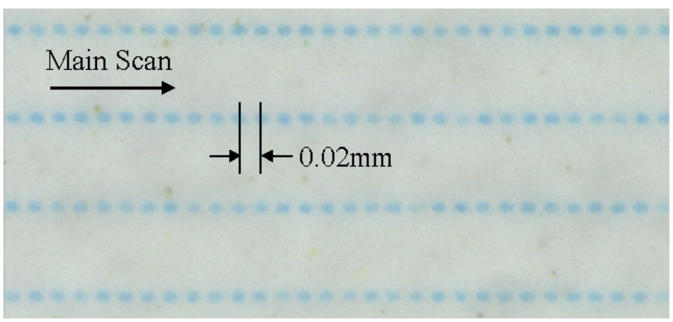


Figure 6. The dots formed on a paper

Highly Accurate Transfer by a Shearing Transfer Method

A color image on the photoconductor is transferred onto the surface of the intermediate roller by a shearing transfer method, followed by transferring onto a paper with the heat and pressure of the pressure roller.

The shearing transfer method does not depend on the adhesive force of the intermediate roller without using electric field. In this method, the velocity of the surface of the intermediate roller is higher than that of the photoconductive drum by several percent. Figure 7 shows the mechanism of the method. A shearing force occurs between a toner layer and the photoconductive drum due to the difference of the velocities. The shearing force compresses and slides the toner layer on the photoconductive drum to transfer onto the intermediate roller. The method is effective and well-directed for a high-resolution image because there is no degradation in quality without toner scattering in an electric transfer method.

The images on a paper observed by a stereoscopic microscope are compared with those on the photoconductive drum to prove the efficiency. As seen in Figure 8, the toner image on the paper is in good agreement with that on the photoconductive drum. The difference of their line widths was observed, but image destruction did not occur due to the transfer. The observation confirms that the shearing transfer method is an excellent method.

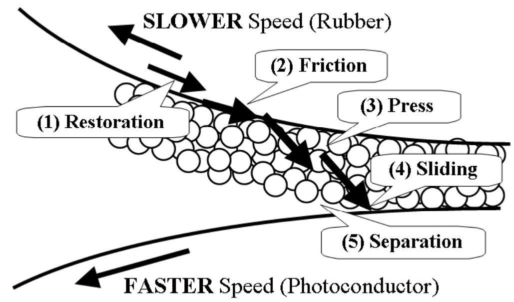
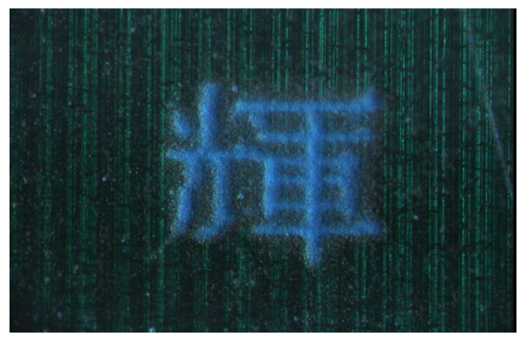


Figure 7. The estimated mechanism of the shearing transfer processs



(a) Image on photoconductive drum (before transfer)

(b) Image on a paper (after transfer)

Figure 8. Comparison of a toner image on the photoconductor and an image transferred on paper (1 point Chinese character)

Full Color Image Creation

The full color image creation was performed with the system including the technologies mentioned above. The following measures were taken to obtain high-quality images.

1. The laser power was modulated to obtain stable dots even if they are separated far from each other and to match each color (Y,M,C,K) with ISO12647.
2. Binary dither processing was used for half-toning.
3. The process speed of transferring was optimized independently of that of developing.

Figure 9 shows one of output images (SCID) with 2,540 dpi and 300lpi created by the system. The objects in the image are printed with great realism. Figure 10 shows the magnification of Figure 9. Figure 11 shows the image with 600 dpi and 200lpi for comparison. Rough patterns are observed in Figure 11. Meanwhile, the dither pattern was created precisely and could not be recognized by the naked eye in Figure 10.

Figure 9. Output image (SCID) with 2540 dpi, and 300 lpi

Figure 10. Magnified view of Figure 9.

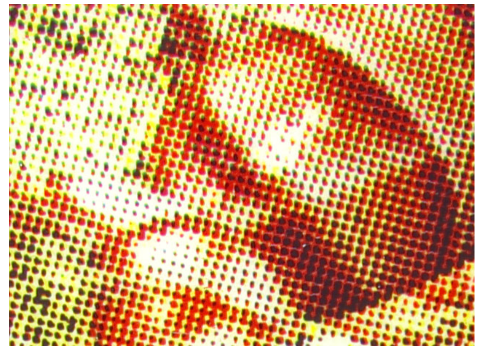


Figure 11. Same image as Figure 10 with 600 dpi, and 200 lpi

The liquid electrophotography system we developed was demonstrated and created the extremely high-quality image with 2540 dpi.

Conclusion

We reported the color image creation by a liquid electrophotography system with 2,540 dpi. The maximum value of the product between the MTF and the maximum power density of the laser beam provided the appropriate laser condition for high-resolution image. Furthermore, the shearing transfer method without electrical energy was shown not to deteriorate the image quality. Finally, using the system we obtained the high-quality full color image comparable to that produced by offset printing.

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Biography

Koichi Ishii received the B.E. degree in electrical engineering and the M.E. degree in medical engineering from Keio University, Yokohama Japan in 1989 and 1991, respectively. Since 1991 he has been with the Corporate Research & Development Center, Toshiba Corp., Kawasaki Japan, where he is engaged in the development of color image processing and electrophotographic imaging processes.