Noise-Reduction Technology for Density Unevenness in Electrophotographic Process

Satoshi Kaneko, Shuji Hirai, Shinji Kato, Terumichi Ochi, Shinichi Akatsu, Takeshi Shintani, Yasuhiro Maehata; Ricoh Co., Ltd.; Ebina, Kanagawa, Japan

Abstract

This paper introduces a noise-reduction technology for density unevenness caused by resistance unevenness of the charge roller in the electrophotographic (EP) process.

Generally, active noise control (ANC) is known to reduce noise in real time. With this technology, the control signal is applied to the noise source in the same physical quantity and antiphase signal of the noise source. To reduce density unevenness by applying this technology for the EP process, it is necessary to move the rotators, such as photoconductors and development rollers, to cancel the fluctuation in the developing gap; however, the moments of inertia of the rotators are too large to respond sufficiently. Against such a situation, we previously developed a control method based on ANC to reduce noise (image density unevenness) in the EP process by applying the control input of different physical quantities from the noise source. With this method, the developing electric field is controlled using the modulation of the developing bias voltage and charging bias voltage instead of making an adjustment in the distance of the developing gap.

In this study, we applied our previous method to the periodic fluctuation in the charging process and developed a noise-reduction method that reduces the periodic image density unevenness caused by the resistance unevenness of the charge roller. With this proposed technology, the surface voltage on the photoconductor is measured by surface voltage sensor without forming toner patterns, the control table is calculated from the detected uneven surface voltage, and the periodic fluctuation is reduced by modulation of the charging bias voltage in real time based on the rotation of the charge roller. The experiments we conducted confirmed that our proposed method improves periodic density uniformity caused by the resistance unevenness of the charge roller effectively.

Introduction

Variable data printing capabilities have helped to expand electrophotographic (EP) printing into the production printing and high-end office printing markets. The Ricoh Company has already launched three types of color print on demand printers since 2008. These products are reputed for having high speed printing capability, being adaptable to various types of paper, and their advanced customer service programs. Naturally, high-quality printing is required in the production printing market, and it is assumed that EP printing can compete with offset printing in terms of commercial printing quality factors such as image density uniformity and stability. As a result, EP printers are becoming increasingly available on this market. To solidify and strengthen EP printing's position in the production printing market, it is essential to improve its image density uniformity.

One problem with EP printing image quality is uneven image density. General EP printers have many noise sources because the EP process uses various complex electric processes. This noise directly affects image quality and occasionally becomes uneven image density on paper. Thus, reducing these noise sources is the best way to achieve offset printing quality.

Figure 1 shows the noise in the sub-scanning direction on a piece of paper. The variable density unevenness occurs on the paper regardless of uniform image data. Easily visible noise has periodic density unevenness caused by rotators such as photoconductors, development rollers, and charge rollers. The main factor of this noise is the fluctuation in mechanical factors such as mechanical accuracy, i.e., the rotation accuracy of the photoconductor and development roller, which is one source of the developing gap fluctuation. This fluctuation will result in periodic image density unevenness on the paper. We have been mitigated this by using high-precision components and reconsidering the manufacturing process; however, to obtain high-quality images, we feel a technical breakthrough is needed. To improve image quality, we attempt to apply the control technology to the periodic image density unevenness in the EP process.

Generally, active noise control (ANC) is known to reduce noise in real time and is widely used to reduce noise in audio devices [1], [2], [3]. It reduces noise with the use of the antiphase sound signal from audio source to cancel noise. The ANC technology is applied for reducing periodic vibration noise in mechanical system as well as in acoustic engineering. In an optical disc drive system, for example, the motion of the optical pickup is controlled to reduce the effect of eccentric rotation of the optical disc [4], [5].

As just described, general ANC technology, the control signal is designed as an antiphase signal of noise source to cancel noise, and applied to noise source in the same physical quantity. To apply the ANC to the EP process to reduce periodic density unevenness, it is necessary to move the rotators to cancel the fluctuation in the developing gap; however, the moment of inertia of the development roller is too large to respond sufficiently.

Against such a situation, we previously developed a control method to reduce the image density unevenness by applying the control inputs of different physical quantities from the noise source [6]. In a previous report, the fluctuation in the developing electric field caused by the rotational inaccuracy of the photoconductor and development roller is controlled using the modulation of the developing bias and charging bias instead of making an adjustment in the distance of the developing gap. This method makes it possible to reduce the periodic density unevenness caused by fluctuation in the photoconductor and development roller.

To improve image quality, we applied the above feedforward control method, and propose a noise-reduction technology to reduce the periodic density unevenness caused by uneven resistance of the charge roller.

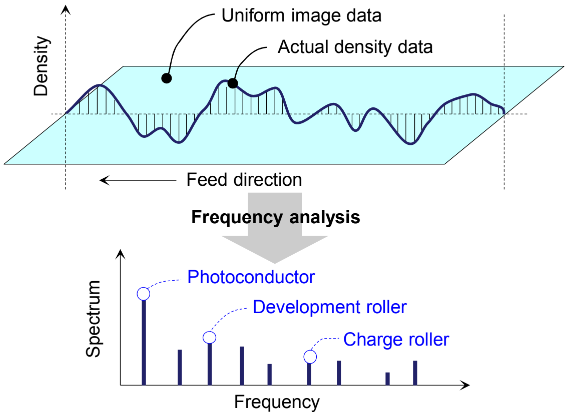


Figure 1. Image density unevenness in sub-scanning direction

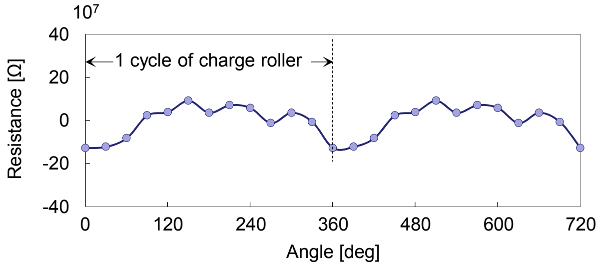


Figure 2. Resistance on the charge roller in circumferential direction

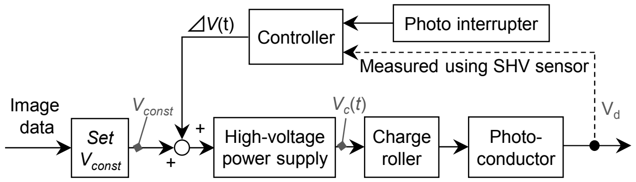


Figure 3. Block diagram of charging process with proposed method

Periodic Density Unevenness caused by Charging Process

It is well known that one of the factors in periodic density unevenness caused by the charge roller is resistance unevenness in the circumferential direction.

Figure 2 shows the measurement results of resistance on the charge roller in the circumferential direction. The evaluation condition is 23.0 deg C and 50.0 %RH, all resistance was measured using a general measurement method that obtains resistance by detecting the current between the charge roller supplied with high voltage and the photoconductor. The charge roller had a difference in resistance in the circumferential direction. The charge roller, which has these characteristics, caused a fluctuation in the charging amount on the photoconductor along with rotational position. This fluctuation resulted in surface voltage unevenness on the photoconductor. This unevenness remained after the exposure process, affecting the developing electric field, finally appears on the paper. This phenomenon particularly affects the image uniformity in the low image density region and does not affect image uniformity in the high image density region. The reason is, in the high image density region, the fluctuation in surface voltage disappears from the latent image after the exposure process due to saturated exposure. Conversely, in the low image density region, the fluctuation in surface voltage remains in the latent image. Thus, the periodic unevenness caused by the charge roller is easily visible in the low image density region.

We confirmed that image uniformity is good as long as the resistance fluctuation of the charge roller is small. These fluctuation occurs in the manufacturing process, and a state of fluctuation changes frequently because it strongly depends on environmental conditions. Thus, it is difficult to detect the resistance fluctuation in the shipment inspection process. For a noise source with such characteristics, a new method for reducing this noise in the charging process is necessary.

Proposed Noise-Reduction Technology

Outline of New Method

Our newly developed method reduces the periodic density unevenness caused by the resistance unevenness of the charge roller by modulating the charging bias on the basis of the rotational period of the charge roller. Modulating the charging bias cancels the surface voltage unevenness on the photoconductor, and forms a uniform surface voltage and toner image.

Figure 3 shows a block diagram of the charging process with this method. The constant charging bias V_{const} is first set after the image data are input in the image-forming apparatus. Next, the pre-determined control table $\Delta V(t)$ from the controller is added in real time to V_{const} and it is input to the high-voltage power supply as the command value. The total charging bias $V_c(t)$ is output from the power supply and charges the photoconductor via the charge roller. The charged surface voltage on the photo conductor $V_d(t)$ is made uniform by $\Delta V(t)$ from the controller. The dashed line shows the learning process of $\Delta V(t)$ in the controller. The controller makes the correction value in suitable timing by measuring the surface voltage on the photoconductor.

This method is similar to our previous method; however, it is better than our previous method for the following two points regarding the density unevenness caused by the charge roller.

The first point is that the proposed method has large signal-to-noise ratio, and our previous method controls the fluctuation of the developing gap. This fluctuation affects the high image density region. However, as mentioned above, the density unevenness caused by the charge roller mainly affects the low image density region. With our previous method, the correction value is calculated from the toner pattern in the high image density region. Thus, it is difficult to extract the periodic density unevenness with this method.

The second points is that the proposed method does not require the toner pattern to obtain the correction value. The density unevenness by resistance fluctuation is strongly affected under environment conditions, especially, increases the surface voltage fluctuation at low temperature and low humidity. Therefore, the controller should remake the correction value under each environmental condition. With the previous method, the toner pattern is required to detect the fluctuation. Forming a toner pattern increases the downtime and toner expenditure.

For the reasons stated above, it is thought that the proposed method is suitable to reduce the density unevenness caused by the charge roller.

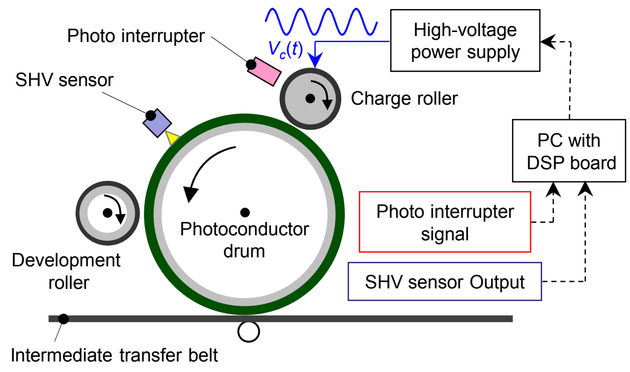


Figure 4. Configuration of experimental setup

Experimental Setup

Figure 4 shows the experimental setup consisting of a general image forming apparatus using a two-component development process. The setup included photoconductor drum, development roller, charge roller, a surface high voltage (SHV) sensor, high-voltage power supply, and intermediate transfer belt. A photo interrupter and personal computer (PC) were added to it as well. The photo interrupters were located close to the rotation axes of the charge roller, and the SHV sensor was located above the photoconductor to measure the surface voltage on the photoconductor. The charge roller rotated based on the rotation of the photoconductor. The PC recorded the outputs from the SHV sensor and photo interrupter synchronously. The sampling time and control period for the high-voltage power supply were both 1ms. The high-voltage power supply, which applies a voltage to the charge roller, was controlled with the PC. Since the PC was equipped with a digital signal processor (DSP) board, the charging bias was modulated on the basis of the control table in real time. All measurements and controls were carried out on the basis of the photo interrupter output.

Design of Control Table

Figure 5 shows a flowchart for determining the control table $\Delta V(t)$ for the charging bias. First, the photoconductor was uniformly charged by supplying the constant charging bias to the charge roller, and the surface voltage on the photoconductor is measured using the SHV sensor. Next, the $\Delta V(t)$ consisting of a periodic component was extracted using Fourier transform and determined on the basis of the photo interrupter output to suppress the uneven surface voltage on the photoconductor, approximated by superposition of sine curves, and expressed as:

$$\Delta V(t) = \sum_{j=1} A_{cj} \cdot \sin(j \cdot \omega_c \cdot t + \theta_{cj}) \qquad (1)$$

where A_{cj} / θ_{cj} are control parameters to modulate for the charge roller, ω_c is the angular velocity of the charge roller, and j is the control order.

Finally, the total charging bias $V_c(t)$ was briefly expressed and given as follows:

$$V_c(t) = V_{const} + \Delta V(t) \qquad (2)$$

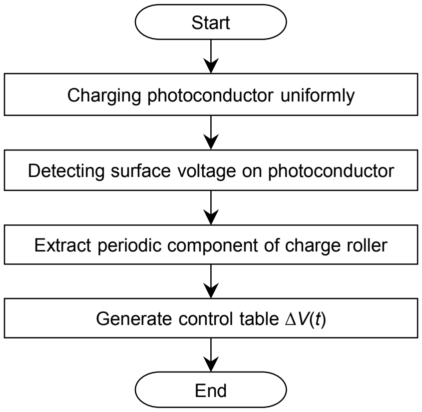
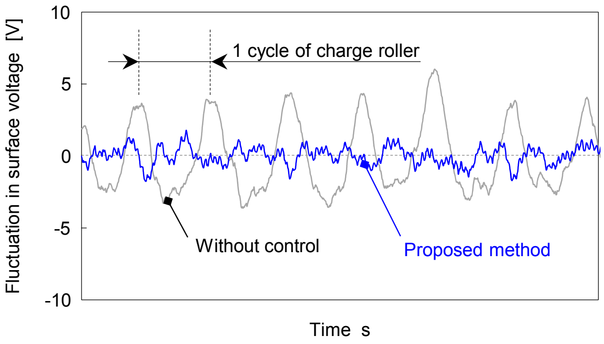
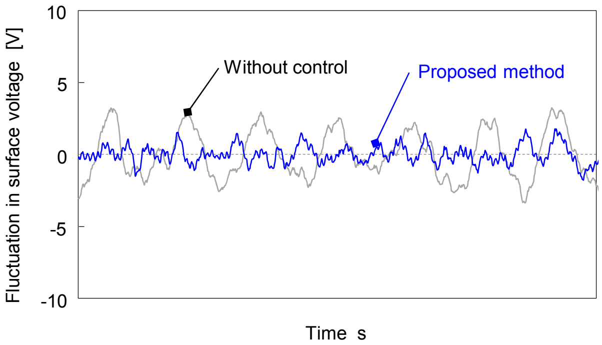


Figure 5. Schematic flowchart of control table in proposed method



(*a*) *Before exposure*

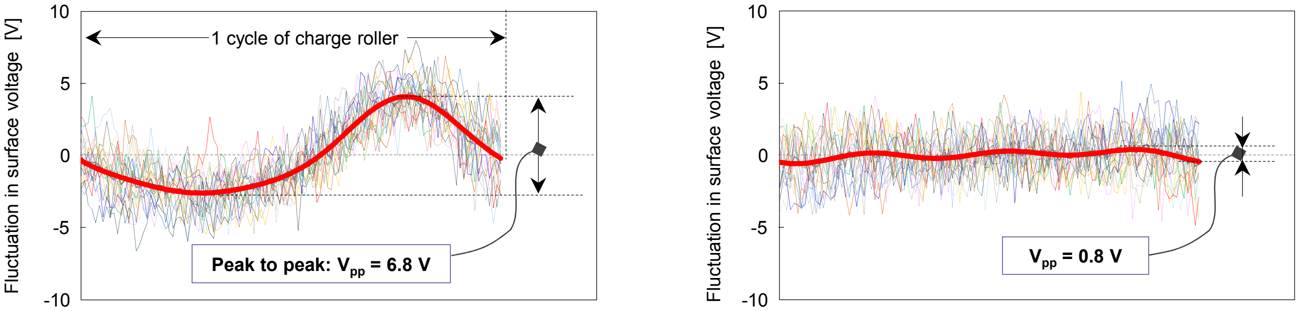


(*b*) *After exposure*

Figure 6. Experimental results of surface voltage on photoconductor

Experimental Results

With our proposed method for reducing the periodic density unevenness, the image forming parameters including V_{const} were determined by process control. All the experiments were repeated several times to confirm measurement repeatability. The surface voltage unevenness was evaluated using the SHV sensor output, and the density unevenness on paper was evaluated using the scanner. And j was chosen to be 3 to express the fluctuation profile of charge roller.



(*a*) *Without control*

(*b*) *Proposed method applied*

Figure 7. Comparison of surface voltage in charge roller cycle

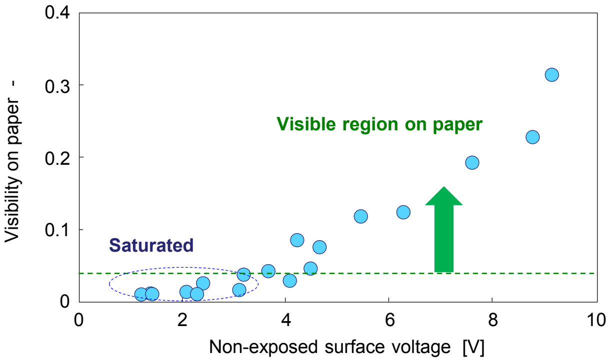


Figure 8. Relationships between surface voltage and unevenness on paper

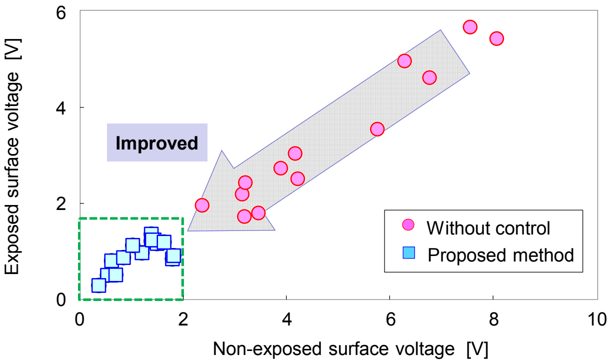


Figure 9. Relationships between non-exposure and exposure voltages

Figure 6 shows the experimental results of surface voltage on the photoconductor. Figure 6(a) shows the results before exposure, and (b) shows those after exposure when 70% uniform density image data were input. Both figures include the results obtained without control and with the proposed method. From the results without control in both figures, the generated fluctuation on the photoconductor remained even after exposure. The toner adhesion was changed periodically because that remaining fluctuation directly affected the developing electric fields. On the contrary, the proposed method successfully reduced fluctuation in surface voltage under both conditions. From these results, fluctuation after exposure was prevented by reducing the fluctuation before exposure.

Figure 7 compares the surface voltages in the charge roller cycle shown in Figure 6(a). Figure 7(a) shows the results without control, and (b) shows the results from the proposed method. As can be seen in both figures, the fluctuation in the charge roller cycle had high repeatability. By comparing both, the peak in fluctuation decreased from 6.8 to 0.8 V by applying the proposed method.

The relationship between surface voltage and unevenness on paper is shown in Figure 8, x-axis represents the non-exposed surface voltage, and the y-axis represents the feature value representing visibility on paper at 70% image density. When this feature value is over 0.5, we can easily determine the image density fluctuation caused by the charge roller. This relationship was obtained by inputting control input forcibly from controller based on the rotation cycle of charge roller. From these results, image density unevenness on paper does not occur when the fluctuation in surface voltage is below about 4 V. It was implied that if the fluctuation in surface voltage is less than about 4 V, it does not affect in latent image.

Figure 9 shows the results of the control effect for various charge rollers. The x-axis represents the non-exposed surface voltage, and the y-axis represents the exposed surface voltage at 70% image density. These plots shows the peak of surface voltage in the charge roller cycle. As can be seen this figure, it is confirmed that the proposed method effectively reduces fluctuation below 2 V, and can suppress various fluctuations. This result means the fluctuation on paper does not occur after applied proposed method.

As these results, we confirmed that our proposed method effectively reduces not only the fluctuation in surface voltage but also that in the exposed surface voltage, finally preventing image density unevenness on paper.

Preferred Application

The periodic density unevenness on paper includes various frequency components. Thus, it is insufficient to apply only our proposed method to comprehensively reduce image density unevenness. The most preferred application is to use both the proposed method and our previous method, which can be used together because both are independent.

Figure 10 shows a block diagram of the above application. The fluctuation in the charging process can be reduced with the proposed method, and that in the development process can be reduced with our previous method. Applying both methods can effectively suppress the various frequency fluctuations caused by rotators; therefore, we can obtain a uniform image.

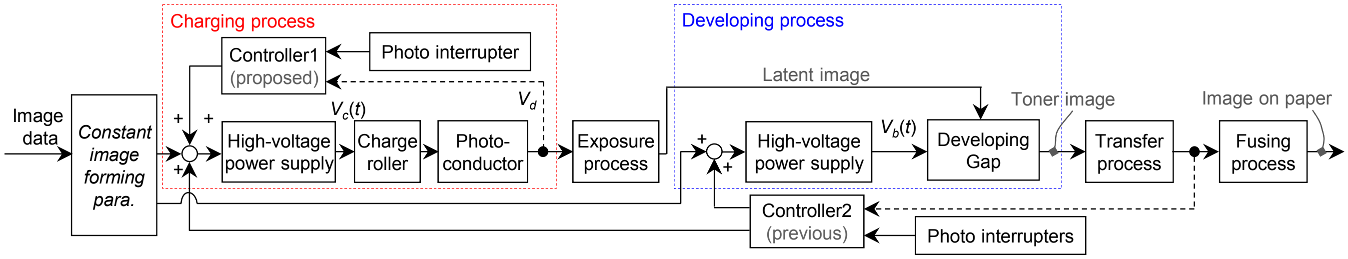


Figure 10. Block diagram of preferred application

Conclusions

We propose a noise-reduction technology for the EP process to reduce the periodic density unevenness caused by the charge roller. The periodic surface voltage fluctuation on the photoconductor was measured using a surface high voltage sensor, and the periodic density unevenness was reduced by modulating the charging bias based on the rotation period of the charge roller. We conducted experiments to thoroughly investigate the reduction in periodic density unevenness obtained with the proposed method and measured its performance under various experimental conditions. The following conclusions were obtained:

1. The surface voltage fluctuation on the photoconductor caused by the charge roller remains after the exposure process, affects the developing electric field, and periodic image density unevenness appears on paper.
2. The proposed method can effectively reduce the periodic fluctuation on the photoconductor caused by the charge roller, and improve the periodic image density unevenness on paper.

We developed two noise reduction technologies for the EP process, which apply ANC, and reduce fluctuation by applying the control input of different physical quantities from the noise source. Applying both methods (previous and proposed methods) to EP printers reduces noise effectively, and enables high-quality print images to be obtained without using any high-precision manufacturing components. These noise-reduction methods have the potential to help EP printers produce high-quality images and accelerate their entry into the production printing market.

References

[1] P. Lueg, “Process of silencing sound oscillation”, U.S. Patent No. 2043416, 1936.

[2] H.F. Olson, E.G. May, “Electronic sound absorber”, J. Acoust. Soc. of Am., vol. 25, no.6, pp. 1130-1136. 1953.

[3] S. Onoda and K. Kido, “Automatic control of stationary noise by means of directivity synthesis”, Proc.6th ICA, F15-3. 1968.

[4] Kiyoshi Ohishi, et al., “Robust Feedfoward Control System considering Sudden Disturbance for Optical Disk Recording System”, IEEJ Transactions on Industry Applications, vol. 124, no.12, pp. 1197-1204. 2004.

[5] D. Koide, et al., “Feed-Forward Tracking Servo System for High-Data-Rate Optical Recording”, Jpn. J. Appl. Phys., vol. 42, pp. 939-945. 2003.

[6] S. Kaneko, et al., “New Technology for Improving Image Density Uniformity in the Electrophotographic Process”, NIP29 and Digital Fabrication 2013, Seattle, Washington, 2013.

Author Biography

Satoshi Kaneko received his A. Eng. from Oyama National College of Technology (2004), B. Eng. from Gunma University (2006), M. Eng. from Tokyo University of Agriculture and Technology (2008) in Mechanical Engineering, and been entered Ricoh Company, Ltd. Since then he has worked in the Imaging Engine Development Division, and engaged in the development and design of process control for electrophotographic printers. He is a member of the Imaging Society of Japan.