Measurements and Analyses of Toner Motion in the Development Process

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Abstract

This report presents a study of the measurements and analyses of toner motion in the development process. By employing a laser sheet visualization technique, toner motions around the spaced single-component development system can be measured. In addition, some quantifying analyses of toner motion were conducted using Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV). In addition to these analyses, the analyzing method of "toner trace tracking" is introduced. This method calculates the virtual toner trace from the velocity map obtained from PIV results. The quantified toner traces have allowed us to compare measurements and calculations, and obtain more accurate model calculations.

Introduction

Electrophotography is the technique that prints images with toner particles. In the electrophotographic technique, spaced-single component development systems, such as the jumping development system, are the simplest systems and are currently used in many copiers and printers. Within this technique, the quality of printed image is greatly influenced by toner behavior in the gap of development nip. To maximize performance, it is essential to understand this behavior. Some previous analytical studies have been conducted, however, these focused on the qualitative behavior of the toner particles. The results were not analyzed quantitatively.

In this report, how toner particles are developed into latent images is observed and analyzed quantitatively using several techniques. The quantified toner motion, its distribution, and quantified toner trace, are obtained from actual observations.

Experimental Set-Up and Captured Images

Figure 1 illustrates the measurement system set-up. This system is the same as what is used in previous reports.[3-5] In this system, the procedure of the capturing video is as follows:

1. Thin "light sheet" (b) lights up the development gap of an electrophotographic process unit (in thin round slices).
2. A high-speed and high-sensitivity camera (a) is attached on the side of a process cartridge, and the camera is set up to be focused onto the planer-illuminated section (light slices).
3. The camera captures reflected light from toner particles only in the planer-illuminated section.
4. By controlling the charging bias of the process unit, various latent images are created on the dielectric drum (instead of a photoreceptor drum).

Because the development gap is illuminated in thin round slices (200 µm thickness), the motions in the direction of the electrophotographic process can be clearly observed. Figure 2 shows captured toner motions developing onto a horizontal line on the dielectric drum. In these images, time intervals are 1/18000 sec. The sequential images show how toner developed into latent images, and how these toners jumped across the gap (500 µm thickness).

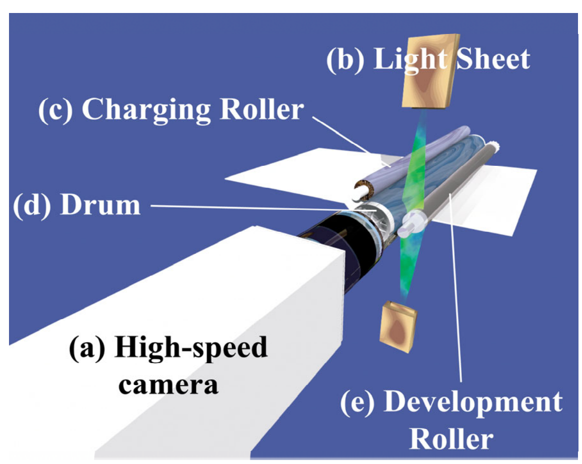


Figure 1. Schematic diagram of the experimental arrangement for capturing toner motions

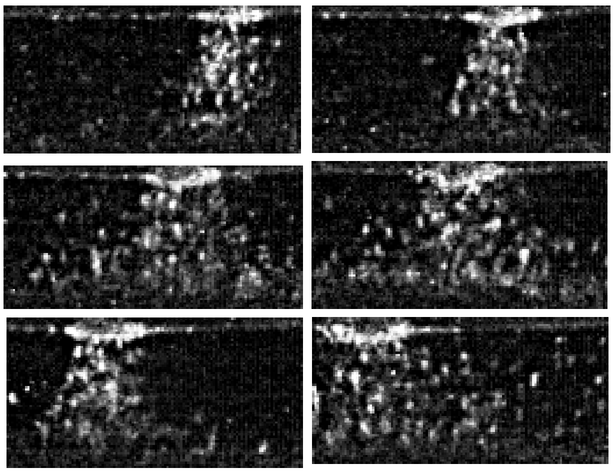


Figure 2. Captured toner motions developing onto a horizontal line on the dielectric drum

Quantification of Captured Toner Motions

To study the behaviors of toner motion, it is necessary to get quantified toner motion from captured toner motion images. Some quantifications are performed using the following methods:

Particle Velocimetry Techniques

There are several "particle velocimetry" techniques which were developed for and mainly used in fluid dynamics. The most common velocimetries from captured particle motion are PIV and PTV techniques.

Particle Tracking Velocimetry (PTV)

In PTV, the velocities of each particle are determined by tracking each particles movement in sequential images. Thus, quantitative information of the movement of each toner particle is obtained. Previously, Hiro-oka et.al. applied these techniques to the measurement of toner velocity in a spaced development system using DC development bias.[6]

Figure 3 shows examples of captured images and the analyzed velocity map from PTV(b). Because too many toners are jumping across the gap, when PTV is applied to the spaced single-component development systems using AC voltage bias, the toner motion is a quickly changeable at every moment and in every position. So, in congested conditions like a solid black area, it is difficult to capture high quality images in which every toner can be distinct from each other or to analyze stable velocity of the toner. However, PTV results show the individual toner information and its distribution. For example, Figure 4 shows velocity distributions on 4 different development bias phase timings A, B, C, D. In the histogram, the right half is the area in which toners are moving from the development roller to the drum surface, and the left side is the area in which toners are moving from the drum to the development roller. In this condition, both positive and negative charged toner particles must be present, because toner particles are both moving and accelerating in opposite directions in the same phase.

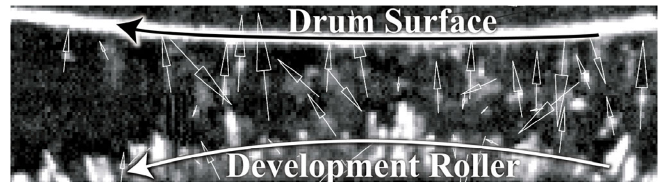


Figure 3. Examples of captured toner motion image and analyzed toner velocity from PTV

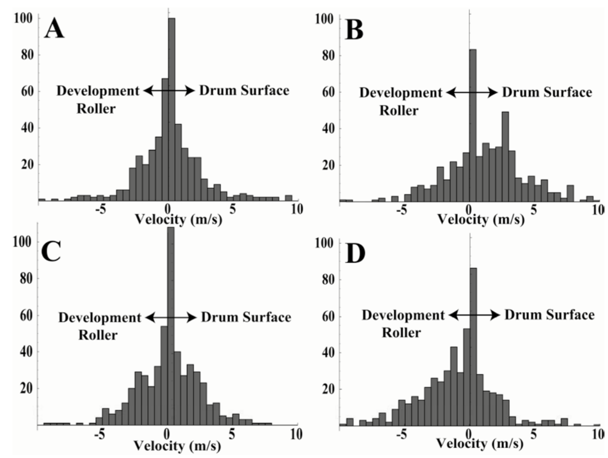


Figure 4. Velocity distributions on four different development bias phase timings

Particle Image Velocimetry (PIV)

In the Particle Image Velocimetry (PIV), velocities are determined by the correlation of each spatial domain in sequential images. By searching the correlative pattern area, each piece of movement information of each area can be obtained. In the toner motion measurements, PIV calculates "averaged" information of the each spatial area in the development gap, and PIV shows no information of each toner particle's movement or any distribution of each toner particle's motion.

Figure 5 shows examples of captured toner motion images and analyzed velocity maps from PIV(b). In analyzing the image, the development gap is divided into an 8 x 32 spatial area, and PIV calculates "averaged" velocities of each section. PIV has more stable results than PTV because analysis is carried out in an area wider than PTV. Even in a congested condittion case, for example in a solid black area, PIV analysis is carried out more stably than PTV.

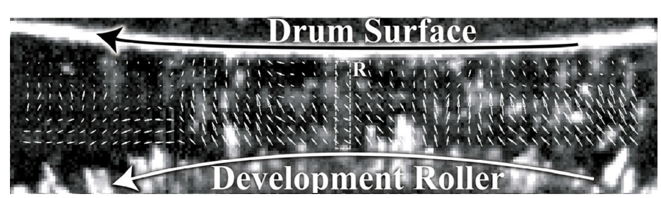


Figure 5. Examples of captured toner motion image and analyzed velocity map from PIV

Figure 6 is an example of velocity alternation [in the rectangular area surrounded by a dotted line "R" in Figure 5 (a)] in development bias phase from PIV analysis. The horizontal axis is time, and the vertical axis is the spatial point from the development roller to the dielectric drum surface.

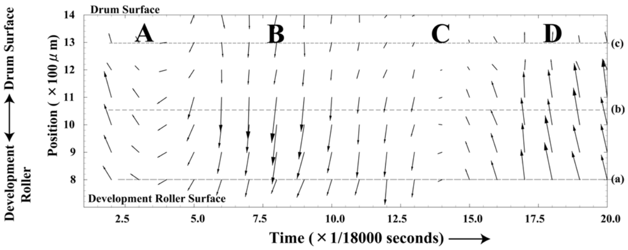


Figure 6. An example of velocity alternation

Figure 7 is another example which shows the responses of toner velocities [(a), (b), and (c)] to the developing bias (d) at the three different spatial points (pointed as (a), (b), and (c) in Figure 4) in the center of the development area. Considerable delay of toner velocities to the development bias (e) is shown in this case.

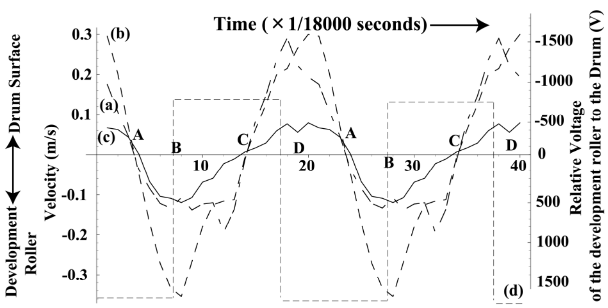
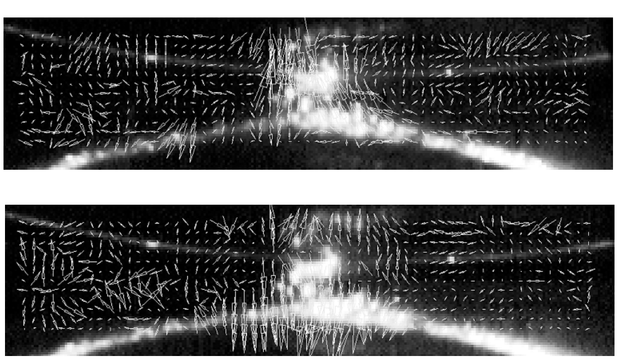


Figure 7. Another example that shows responses of toner velocity to the developing bias

Figure 8 shows each analyzed toner velocity as a horizontal line image develops at the positive bias moment (a) and the negative bias moment (b). Figure 9 shows analyzed toner velocities of particles nearby a two dot (600dpi) line latent image (a) and a solid black image (b).

(a)



(b)

Figure 8. Analyzed toner velocities when toners are developing onto a horizontal line image

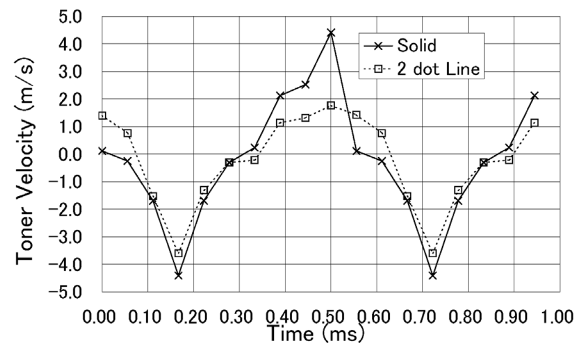


Figure 9. Analyzed toner velocities at the point nearby two dot (600dpi) line latent image (a) and solid black image (b)

Differences between PTV and PIV

Figure 10 shows the results obtained by using PIV (a) and PTV (b) analysis of the same captured toner motion image. The velocity values obtained from PTV are two times greater than the values obtained from PIV.

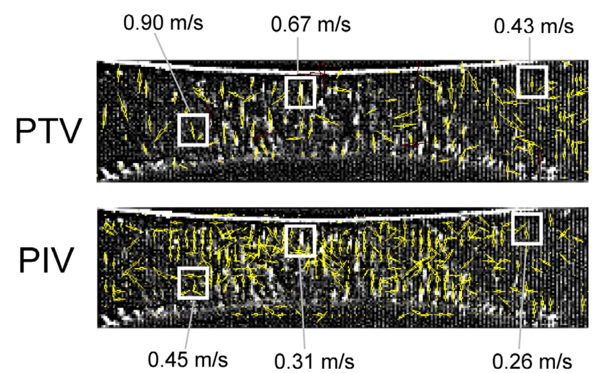


Figure 10. The difference in results obtained by using PIV (a) and PTV (b) analysis from same captured toner motion

The most basic reason for the difference is considered to be that the brighter particles, which are easily captured and measured by PTV and PIV analysis, are not always "average" toner but usually "big or bright" toners which have relatively faster velocities than "average" toners. And, an influence of such effects on analyzing in PTV is stronger than in PIV.

Decomposition of Toner Traces from PIV Results

PTV can track toner particles at one moment. However, there are many difficulties in obtaining toner traces sequentially or stably from PTV. On the contrary, PIV results are more stable even in crowded conditions (i.e. there are too many toner particles), but PIV does not track each particle. It calculates velocities not of each toner particle but each separate area in the development area.

To track "toner traces" stably, the decomposition of toner traces technique is investigated. In this technique, toner traces can be estimated by utilizing velocity vector maps at each time which can be analyzed from PIV.

Figure 11 shows the procedure to estimate toner traces from velocity vector maps.

1. At first, an arbitrary velocity vector map is picked up (a).
2. Assume there is a "virtual" toner on the velocity map, and it is in the appropriate position (b).
3. Based on the movement, which is shown by the velocity vector map, the "virtual" toner is moved to subsequent position (c).
4. By repeating the calculation routines (2) and (3), a continuous trace of the "virtual" toner can be estimated.

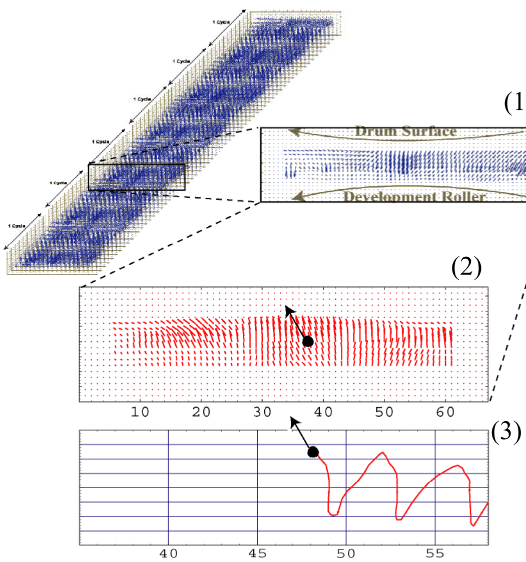


Figure 11. The procedure to estimate toner trace from velocity vector maps

Thus, by integrating these sequential velocity vector maps, "virtual standard toner traces" can be estimated. This decomposition of continuous toner traces allows us to make "reference traces" which can be easily compared to calculation results. Figure 12 shows an example of a "virtual toner trace" under the development bias in the center of the development area.

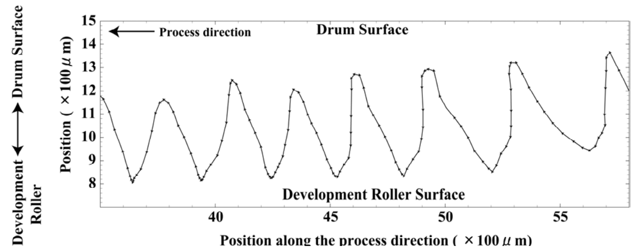


Figure 12. An example "virtual toner trace" under development bias

Conclusion

Detailed motions of toner particles in the spaced single-component development system are clearly captured. And the toner motions and their distribution in several conditions are quantified by PIV and PTV analyses. From the results, differences between PIV results and PTV results are discussed.

Moreover, based on PIV results, analysis for the decomposition of toner traces is suggested and investigated. The "Virtual Toner Trace" technique, which is similar in form to calculated results are easily compared with them, is easily obtained.

References

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Biography

Jun Hirabayashi received his M.S. in Geophysics from Kyoto University in 1994. Since 1994 he has worked in the Electrophotography Research Center at CANON INC. His work has primarily focused on the electrophotography development process. However, he is interested not only in the development process but also in the entire electrophotography image forming techniques and machines. He is a member of the Imaging Society of Japan.