Optical Measurements of Toner Motion in a Development Nip

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Abstract

Many electrophotographic printers use brushes of magnetic carrier particles in direct contact with a photoreceptor to develop electrostatic images. Toner particles move from the carriers to the photoreceptor in the presence of the latent image development field. Recent color electrophotographic printers such as the HP Laserjet color printer use a spaced single component development system where the toner supply does not directly contact the photoreceptor, but instead is transported across a gap by electric fields. In these systems, one can directly observe the toners traversing the gap by viewing images of light passing through the development nip. We have designed a system where we capture the image of the transmitted light with a high resolution, 255 gray level CCD camera. From these digital images, we can quantitatively extract the toner density and velocity as the particles traverse the nip. Using time delay photography with microsecond resolution we measure the response of the cloud to incoming images. Using organic film designed to hold charge on a permanent latent image we are able to capture images of fine line development. Quantifying the density and motion of toners in a gapped development nip has allowed us to generate accurate physical models.

Monocomponent Development

In dual component development systems, toner is transported to the development nip on larger, magnetic carrier particles. The carriers provide a means to charge, contain, and transport a large number of toners for development.

A simpler system used in many low end products is monocomponent development, where the charged toner is transported to the development nip on a roll [1]. An image develops when the charged toner contacts an oppositely charged area on the photoreceptor (touchdown development). Alternatively, a gap can be placed between the photoreceptor and the donor and the toner can jump across the gap to develop out. To improve image quality, a powder cloud can be generated in the nip region. The toner can be removed from the donor with a combination of mechanical and/or electrostatic means and suspended in the nip region. Toner is pulled from the cloud reservoir to develop a latent electrostatic image.

Cloud Visualization

Optical measurements of toner in the development nip of gapped monocomponent systems provide a means to quantitatively probe the development process. In figure 1, we show the experimental setup used to monitor the development of toner. Similar techniques have been used in other optical investigations of the development nip in monocomponent development [2].

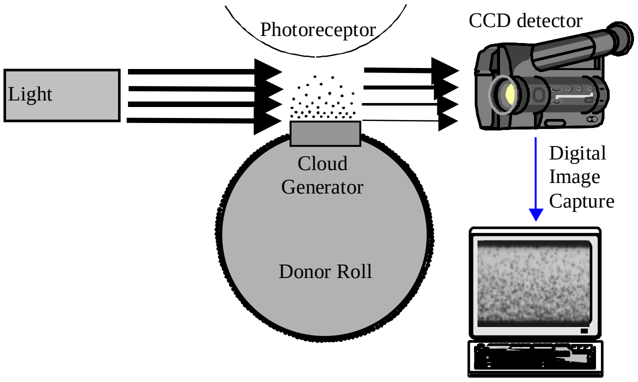

Figure 1. Cloud visualization technique

The cylindrical donor roll is shown in cross section in the figure. It is loaded with charged toner and rotated to bring the toner to the development nip. At the 12 o'clock position is a cloud generation mechanism, where toner is removed from the donor and placed in the nip. In most of our experiments, a metallic cylinder is used as a surrogate for the photoreceptor and biased to cause or prevent development.

White light is transmitted through the nip region. The light source is placed far from the nip to insure uniform illumination over a small region. A long working distance lens is attached to either a video camera or a still camera and focused on the nip. If the depth of focus of the lens is greater than or comparable to the width of the powder cloud (the left-right distance in the figure), then the light collected will depend on the density of toner at a particular point in the nip.

Figure 2 shows a typical image for a powder cloud when the receiver (photoreceptor surrogate) is biased to suppress toner development on the left and develop toner on the right (this is done with printed electrodes on mylar). The top of the image is the bottom surface of the receiver, while bottom of the image is the top of the toner supply surface. The exposure time of the image is much longer than the toner transit time, so that each point in the image measures the time averaged toner density at a particular point in the nip. The image shows that the toner in the powder cloud stays close to the donor unless it is developing to an image.

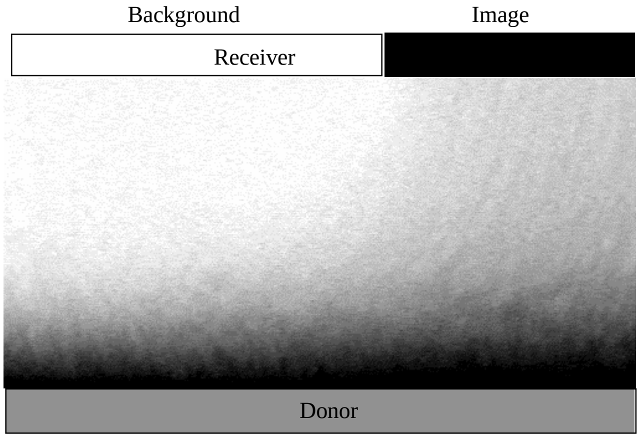

Figure 2. Image of static and developing cloud. Darker areas have more toner.

For clouds with a low volume fraction of toner, the light transmitted is proportional to the number of toners in the cloud. Consider, a cross-section area a_{cs} of the cloud which contains N toner particles in width w. Assuming spherical particles, in the low volume fraction limit, light absorbed by each particle is proportional to the area of a disk, i.e. πr^2, where r is the particle radius. Thus the attenuation of light through the cloud is $a = N\pi r^2/a_{cs}$. Now the volume fraction is $\phi = NV_p/(a_{cs}w)$, where V_p is the volume of a toner particle, i.e. $V_p = 4\pi r^3/3$. Thus attenuation is $a = 3\phi w/4r$, and in the limit $\phi \to 0$, $da/d\phi = 3w/4r$.

For higher volume fractions, the transmitted light obeys Beer's law [3] and the attenuation may be written as $a = 1 - \exp(-\alpha\phi)$, where α is a constant. In the limit as $\phi \to 0$, $da/d\phi = \alpha$, thus $\alpha = 3w/4r$. The volume fraction is, therefore, $\phi = -4r * \log(1-a)/3w$.

Cloud width, w, and volume fraction of toner, ϕ, can both vary as a function of the height, z, above the donor, and location, x, along the donor. The image wise attenuation, a(x,z), is measured by comparing the transmitted light intensity from the camera signal with and without toner in the nip. The number density projected onto the x-z plane, N(x,z,), can then be calculated from a(x,z). Independent measurements of the cloud width are used to get lower resolution three-dimensional information.

Extraction of Toner Velocities

Measurement of the velocities of individual toner particles as they traverse the nip aids in understanding the development process. The balance between electrostatic forces and the Stokes drag force associated with air resistance determines the terminal velocity of toner particles. Understanding the interplay between these forces gives information about how development changes for different size toner particles in different electric fields.

The toner velocity is determined by taking an image of the development nip at a shutter speed of 100 μsec. A series of images taken at different development voltages between the donor and the receiver is shown in figure 3.

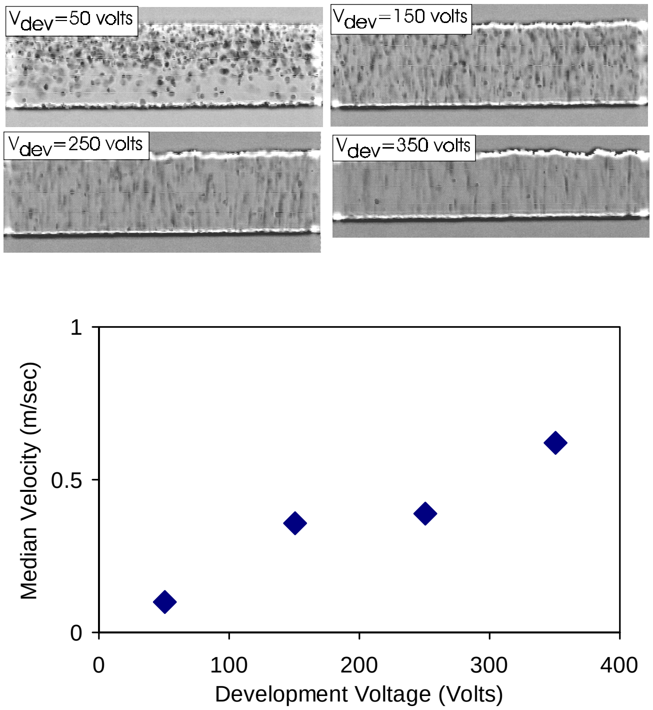

Figure 3. Median toner velocities determiend from imaging toner streaks

The path length of 20 toner particles in each image was determined. There is a distribution of path lengths, because there is a distribution of charge and size on the toners. The median velocity determined from these images is plotted as a function of development voltage. Analysis of the electric field dependence of individual toner velocities within the Stokes drag limit leads to accurate physical models of monocomponent development.

Cloud Response Time

The response time of a toner cloud to a moving electrostatic image has direct consequences for image quality. For example, imagine a single pixel latent image running parallel to the donor roll coming into the nip. If the cloud responds too slowly, the line will pass through the nip before the cloud can rise, and the line will be underdeveloped. Another example is an edge of a solid parallel to the donor roll. Part of the edge may pass through the nip before the cloud rises to start developing and the leading edge of the image will not be fully developed.

To monitor the cloud response time, we perform the experiment described as follows: The receiver is a metallic roll and biased to repel toner. At time zero, the receiver voltage is switched to a developing field. At an adjustable time Δt after the receiver roll bias is switched, an image of the cloud is taken at the shortest possible shutter speed. The experiment is repeated for a series of Δt's, from $\Delta t=0$ to a large Δt at which the development is occurring to completion. A subset of these images for a particular value of voltage differences across the nip is shown in figure 4.

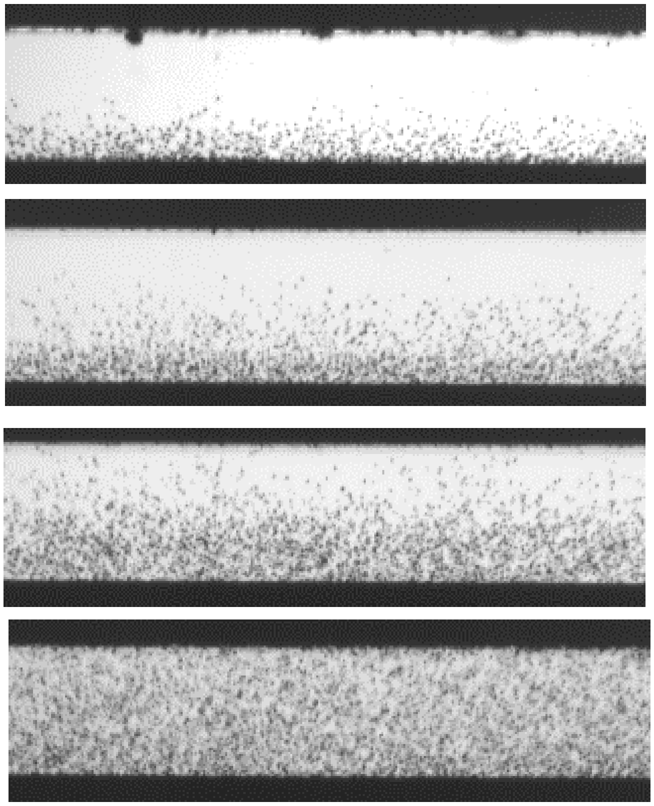

Figure 4. Cloud taken at Δt = 12.5μsec, 120 μsec, 180 μsec and 480 μsec after development begins.

From these images, we can extract the midpoint of the cloud. The midpoint of the cloud is defined as the point where 50% of the toner is the visible nip region lies below this point and 50% of the toner lies above this point. The cloud midpoint will rise as the cloud rises to develop an image. The 50% midpoint vs. Δt is plotted in figure 5.

The diamonds are the metrics from the individual images, and the solid line is a fit of the function $f = h_0 + \Delta h(1-\exp(-\Delta t/t_0))$ to the data, where h_0 is a measure of the initial height of the cloud, and t_0 is a measure of the temporal response of the cloud to the development field. We have used this technique to study the sensitivity of the cloud response time to electric field strength and toner charge to mass ratio.

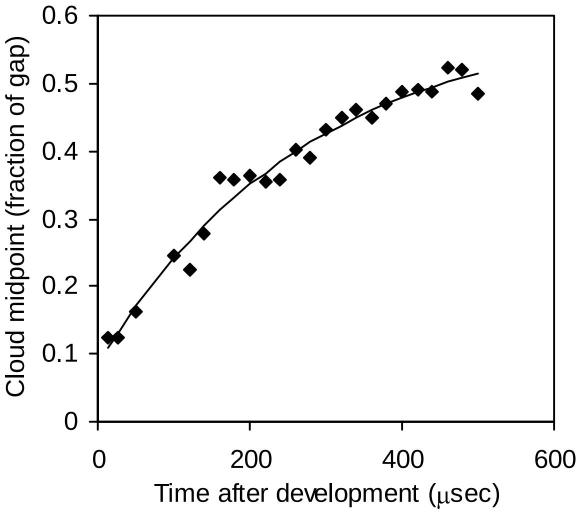

Figure 5. Cloud midpoint response to development

Development of Fine Lines

High quality printing requires the accurate development of fine lines. Line shrinkage or line growth can occur if the development parameters are not optimized. The cloud visualization technique can be used to examine the relationship between the cloud and the line widths developed.

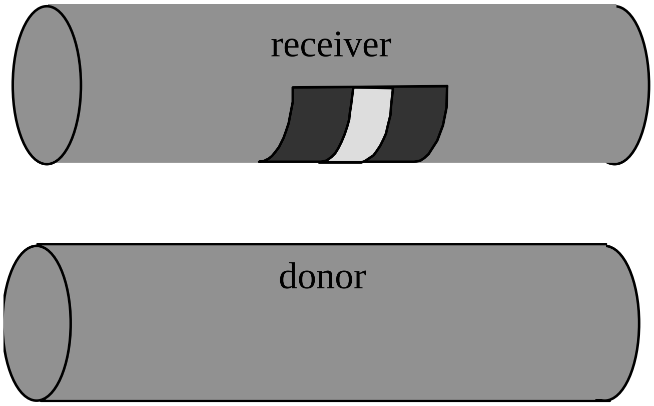

Figure 6. Setup for line measurement

Line width optimization experiments were done without a laser raster optical scanner and a photoreceptor by attaching a special material call Verde Film, which has a permanent latent image. Areas of the Verde Film that have been exposed to ultraviolet light are unable to hold a charge [4]. An electrostatic latent image can, therefore, be created by charging a biased film.. We used a film upon which a 100 µm wide line was written and attached it to the receiver as shown in figure 6.

As the line passes through the develop nip, toner is pulled from the cloud and develops to the line. An image of this process is shown in figure 7. The bump going down on the center of the receiver roll is an image of the developed line looking edge on. The image of the gap to either side of the developing line is lighter at the top, indicating the cloud resides near the toner supply surface in regions where no image is being developed.

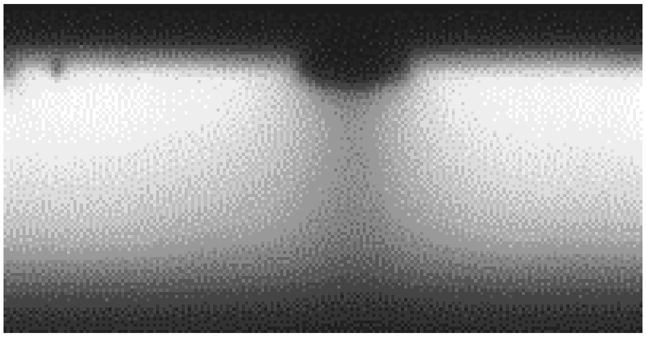

Figure 7. Toner developing fine line

The height of the line as a function of position along the receiver can be determined from the digital image. The full width of half-maximum of this profile can be taken as the line width. A dark region in the image can be observed extending from the cloud to the developed line. The width of this darker region increases closer to the powder cloud supply. Its shape is similar to the dust entrained in a tornado emanating from a cloud, but inverted. This dark region is the toner being pulled from the cloud to develop to the line. It is wider near the bottom because toner is being pulled from regions of the cloud greater than the line width.

Conclusions

Improving image quality for a development process consists of changing parameters of the development system and observing any beneficial change on the image quality. Models of the development process have assisted in identifying and understanding what controls image quality.

Cloud visualization allows for a more accurate link between system image quality performance and physical mechanisms. Visualizing the toner motion in the nip can not only be used to monitor image quality, but also to gain a better perspective of how toner motion can be controlled. In addition, being able to quantify toner densities, and monitor individual toner velocities and the dynamics of the cloud has allowed the development of accurate single particle models of development which have been used to simulate the development process from first principles [5].

References

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Biography

Howard Mizes received his B.S. degree in Physics from the University of California at Los Angeles in 1983 and a Ph.D. in Applied Physics from Stanford University in 1988. His thesis work was concerned with the electronic structure of materials probed with scanning tunneling microscopy. Since 1988 he has worked in the Wilson Center for Research and Technology at Xerox Corporation in Webster, NY. His work has primarily focused on the development process, and includes toner adhesion, toner transport, and image quality issues.

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