Measurement Method of Toner Mass Distribution by Reflectance Using Multiple Exposure

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Abstract

It is important to measure the toner mass distribution on paper, on intermediate transfer belts and on OPCs (organic photo-conductors) to analyze the structure of the toner image in electrophotography. However, toner distributions are difficult to measure. When the amount of the black toner is high, the reflectance is very low. Therefore, a charge-coupled array (CCD) camera cannot detect minor differences in the reflectance. Additionally, when the exposure time is long, the signals from the paper are saturated. The purpose of this paper is to establish a toner mass distribution measurement method. To archive this, we propose a measurement method using a multiple exposure. First, the toner area and the paper are measured by the multiple exposure process. Next, based on the relationship between the exposure time and the brightness values of the CCD camera, two approximately linear equations are obtained by the least squares method and the two lines slopes are obtained from these equations. The toner reflectance is calculated using the line slopes. If we calculate the reflectance at each pixel of the camera, then the reflectance distribution can be obtained. This method can prevent detection shortages and saturation of the camera to enable measure toner and paper measurements while using entire the dynamic range. Furthermore, the method can reduce random noise to calculate the reflectance using multiple images of the same area. Finally, we propose an unfixed toner mass prediction model. This model can vary the reflectance relative to the toner mass, and the toner mass distribution can thus be obtained. This method can visualize the uniformity of the toner mass, and we expect this method to be used for image analysis.

Introduction

The uniformity of the toner mass distribution on the paper, the intermediate transfer belt and the OPC (organic photo-conductor) is one of the factors that affect graininess [1-2] in electrophotography (EP). It is therefore important to measure the toner distribution for analysis of image graininess.

In general, the amount of toner that adheres to the paper and the belt is measured by suction (Figure 1). The toner particles are sucked up by a pump before fixation and are then weighed. The adhered amount per unit area is calculated based on the suction area. However, this method can measure only the average amount of toner in the suction area. Additionally, the measurement method is destructive.

Alternatively, the laser scanning microscope (LSM) can be used to measure the toner mass distribution. The toner height on sheet is measured by LSM and the distributions of the mass and the layer thickness are calculated from the measured toner height. However, the LSM measurement range is small (less than 1 mm square) and is insufficient for analysis of the graininess.

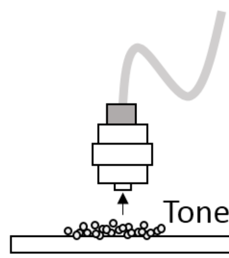

Figure 1. Toner mass measurement process

Image graininess shows high correlation with density fluctuations at a low frequency. The frequency range is no more than 1 cycle/mm [1]. It is also difficult to measure the toner mass accurately because of micro gloss noise [3-5]. While an area camera can measure a large part of the toner image, it is difficult to detect black toner distributions because of their very low reflectance. At present, no method has been developed that enables easy measurement of the toner mass distribution at the low frequency.

The purpose of this study is to develop a camera system that can measure the toner mass distribution on a paper accurately. The proposed system has the following three technical features.

1. Multiple exposure
2. Removal of gloss
3. Toner mass prediction model

Multiple Exposure Method

We propose a method to measure reflectance using a multiple exposure to detect the light reflected from the black toner. The multiple exposure method can reduce the random noise and calculate the reflectance using multiple images of the same area. Furthermore, the method can prevent detection shortages and camera saturation to measure both toner and paper while using the entire dynamic range.

First, we explain the conventional measurement method. Figure 2 shows the measurements of a solid image and paper using a single exposure. Here, I is the intensity of the incident light, Rp is the reflectance of the paper, Rt is the reflectance of the toner, and t is the exposure time. S_0 and S are the output values of the optical detector and are given by Eqs. (1) and (2).

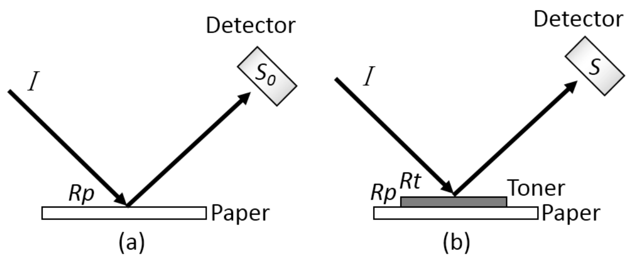

Figure 2. Light reflection measurement of toner and paper. (a) Reflection from the paper. (b) Reflection from the toner and the paper

$$S_0 = I \cdot Rp \cdot t \quad (1)$$
$$S = I \cdot Rp \cdot Rt \cdot t \quad (2)$$

The reflection from the toner (Rt) is calculated from S/S_0. However, in this method, S decreases when the amount of toner is high. If we increase the exposure time to detect the low reflection of the toner, then the output value S_0 from the paper is saturated.

Next, we explain the proposed multiple exposure method. Figure 3 shows the relationship between the exposure times and the detector output values.

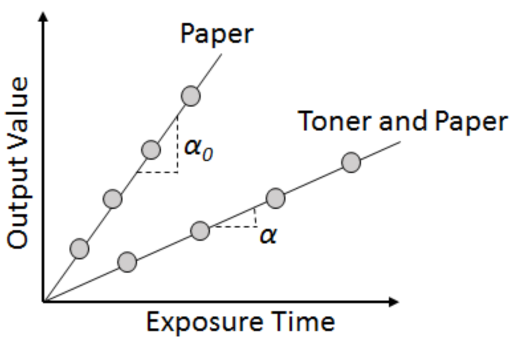

Figure 3. Relationship between exposure times and sensor output

The toner and paper are measured at different exposure times $t(i)$ in the range where the captured data is not saturated. Here, i is the number of exposure measurements.

S_0 and S are given by Eqs. (3) and (4):

$$S_0(t) = I \cdot Rp \cdot t(i) \quad (3)$$
$$S(t) = I \cdot Rp \cdot Rt \cdot t(i) \quad (4)$$

Because the relationship between $S_0(t)$-$S(t)$ and $t(i)$ is linear, the slopes α_0 and α are given by Eqs. (5) and (6) below. Therefore, the toner reflectance Rt is given by Eq. (7).

$$\alpha_0 = I \cdot Rp \quad (5)$$
$$\alpha = I \cdot Rp \cdot Rt \quad (6)$$
$$Rt = \alpha / \alpha_0 \quad (7)$$

The two slopes, α and α_0, are obtained as follows. Based on the relationship between the exposure times and the output values, two approximately linear equations are calculated using the least squares method and the two slopes of the lines are obtained from these equations.

The slopes are calculated for each pixel of each images captured by the measurement device and the reflectance distributions are obtained by calculating Eq. (7). The random noise then decreases because the reflectance is calculated based on multiple images of the same area.

Measurement Device

Figure 3 shows a schematic illustration of the measurement device. The device is composed of a charge-coupled device (CCD) camera and a ring illumination device. Because the measurement geometry is at 0°, the measurement device is small in size and the camera angle adjustment process is simple.

Additionally, polarizing filters are inserted into the optical path of the camera system, located orthogonal to each other, to measure the toner only internal diffuse reflection. While the toner surface has a polarization characteristic, the internal diffusion has no polarization characteristics. It is therefore possible to remove the gloss component (the surface reflection) using these filters.

Table 1 shows the device configuration. The camera is a three-CCD camera with 12-bit depth. The captured image resolution is approximately 2900 dpi and the sampling pitch is 8.8 µm. The measurement area is 12×9 mm. The brightness of the Green channel was used for the reflection calculations.

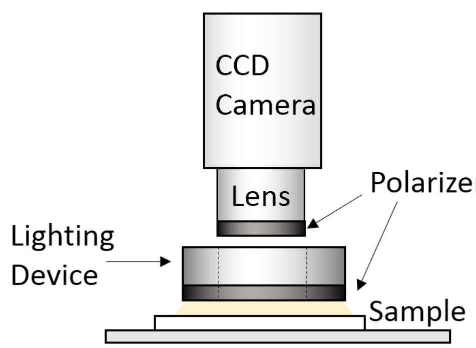

Figure 4. Schematic illustration of the device

Table 1 Device configuration

Camera	C7780-20 (Hamamatsu Photonics K.K.)
Lighting Device	LDR2-50-SW (CCS Inc.)
Lens	AE20B2 (FUJINON) MAF75B (FUJINON)
Polarizer Filters	PL-LDR-50 (CCS Inc.) 52-S-PL (Kenko Tokina Co., Ltd.)

Measurement Precision Verification

A verification experiment for the measurement method was then carried out. The samples used were evaluation charts of uniform density made from silver-halide photographic materials. The density values were 0.189D (sample A) and 0.977D (sample B). The verification flow is as follows.

1) The reflectance values of samples A and B are measured using a colorimeter (X-RITE 939, made by X-Rite, Inc.). Here, the reflectance of sample A is R_1 and that of sample B is R_2.
2) The slopes of the samples (α_1 and α_2) are measured via the multiple exposure method and are calculated.
3) We confirm that $R_2 = R_1 \cdot \alpha_1 / \alpha_2$ (8)

We used the average brightness values of each pixel for comparison with the values measured by the colorimeter. The colorimeter measured value of R_2 was 0.105, and the value of R_1 was 0.647. Figure 5 shows the results of the multiple exposure measurements. The approximately linear equations were calculated using the least squares method and the slopes were obtained from the equations above (α_1=10370, α_2=1768.6). We confirmed that the linearity of the exposure time and the brightness were both high.

Next, we calculated R_2 from R_1 and the slope values using Eq. (8). The calculated result was 0.110. The error between the measured value and the calculated value was 0.005. We thus confirmed that this method can calculate the reflectance accurately.

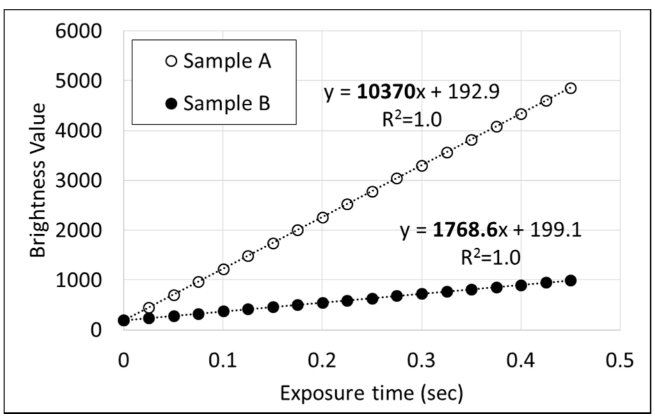

Figure 5. Relationship between exposure time and brightness value

Comparison with Single Exposure

Next, we compared the accuracies of the single exposure and multiple exposure methods. An evaluation sample was measured 10 times by the single and multiple exposure methods, and the reflectance was then calculated. Finally, the variations in the reflectance were compared. The sample was a solid black image that had been printed by EP. The paper was "TYPE6000 70W" fine paper (RICOH). The toner mass per unit area that was measured by suction was 0.66 mg/cm^2, and the density measured by the colorimeter was 1.738.

Figure 6 shows the mean and the standard deviation σ of the reflectance. The variation of the multiple exposure method is one quarter of that of the single exposure method.

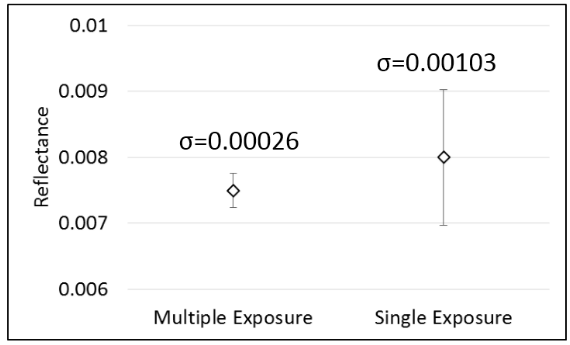

Figure 6. Reflectance of multiple exposure and single exposure

Toner Mass Prediction Model

We proposed the toner mass prediction model based on the relationship between the amount of unfixed toner and the reflection measured using the multiple exposure method. This model can convert the reflectance to give the toner mass.

The relationship was obtained experimentally. We measured unfixed solid black images containing various amounts of toner using both the multiple exposure method and the conventional measurement device. Then, we weighed the toner amounts by the suction method. The black toner samples were made by an experimental machine that was developed in-house.

The results of these measurements are shown in Figure 7, including the results from the single exposure method. The sensitivity of the single exposure method is poor in the high mass range. In contrast, the sensitivity of the multiple exposure method is not saturated.

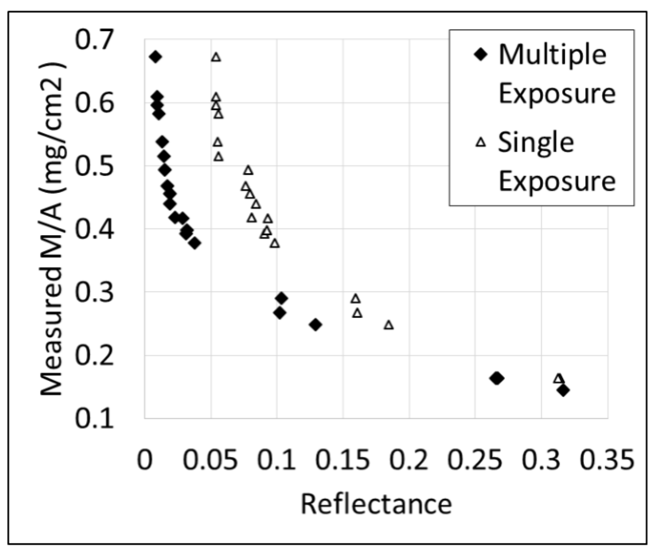

Figure 7. Relationship between measured M/A and reflectance

We assumed that the image density is proportional to the amount of toner and proposed our prediction model of the toner mass per unit area *(M/A)* based on the results shown in Figure 7, where

$$M / A = p_1 \cdot \log(R + p_2) \quad (9)$$

Here, R is the toner reflectance. p_1 and p_2 are parameters that are calculated from the measured M/A: p_1 is the parameter used to convert the density to the amount of toner, and p_2 is the parameter that represents the internal diffuse reflection. p_1 and p_2 were determined via a nonlinear regression analysis (p_1 = -0.230, p_2= -0.0064).

Figure 8 shows the results from the prediction model. R^2 was 0.9939.

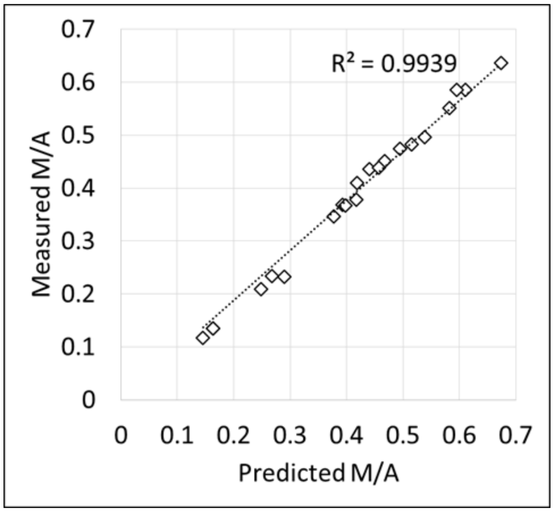

Figure 8. Measured and predicted values of M/A.

Next, we use the prediction model to convert the reflectance of the unfixed toner image into the toner mass distribution. We calculated the reflectance in each pixel of the previous samples to obtain the reflectance distribution. Figures 9 and 10 show the mass distributions of a solid black image on the paper. Figure 9 is the normal mass image (average M/A = 0.417 mg/cm^2) and Figure 10 is the high mass image (average M/A = 0.673 mg/cm^2). We were thus able to visualize the toner mass distributions.

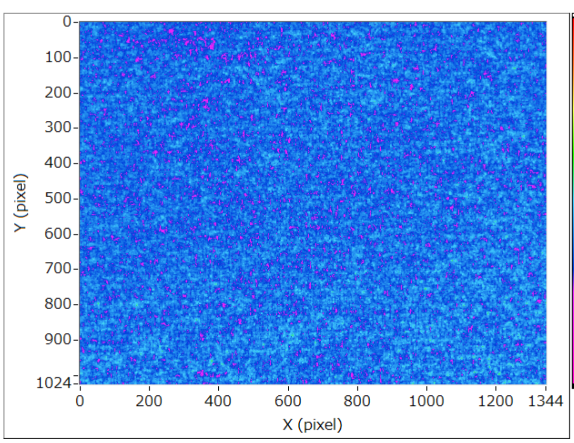

Figure 9. Toner mass distribution (average M/A = 0.417 mg/cm^2)

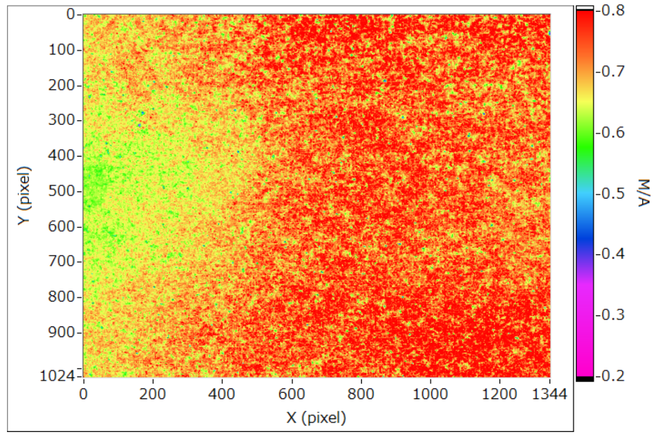

Figure 10. Toner mass distribution (Average of M/A = 0.673 mg/cm^2)

Conclusions

A toner mass distribution measurement method based on reflectance and using multiple exposure has been developed. The variation of this method is smaller than that of the conventional method. We also proposed an unfixed toner mass prediction model for toner on paper. The proposed model can change the reflectance relative to the toner mass distribution. This method can be used to visualize the uniformity of the toner mass, and we expect that this method will useful for image analysis application.

In our future work, this method will be applied to measurement of the toner distributions on the intermediate transfer belt and the OPC in the EP process.

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Author Biography

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