Analysis of Idle Time Effect on Color Consistency of Electrophotographic Printer

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Abstract

This study analyzes idle time effect on a color electrophotographic (EP) printer. The idle time effect is defined as color or tone variations between the prints before- and immediately after- a printer having been idle for an extended period of time. In the study, 15 hours of idle time, which is regularly experienced in an office setting from 5pm to 8am, is investigated. Four off-the-shelf printers of the same model were placed in a temperature controlled environment with their engine calibration disabled. First, a preliminary experiment to know the inherent printer characteristics was conducted. With the preliminary experiments, the design of the experiments for the idle time effects was determined and total 39 sets of experiments were performed. More than 75% of the cases showed statistically significant tone differences, which are greater than 2 $\Delta E76$ from paper white, for test pages printed before and after the idle time. It is also shown that these tone variations diminished once three pages have been printed after the idle time ends.

Introduction

In an office-like environment, it is easily experienced that the first several prints of the day are not exactly rendered in terms of the tone of the colors. For example, suppose that a user wants to print a 60% gray level box figure in the morning. If the printer was not turned off during the previous night and the printing job is the first job on the day, the print-out may not show the 60% gray level box. Assuming that the printer has been turned on during the previous night, the printer idle time can be thought to be the only cause which affects the printer behavior.

Two categories of factors which affect printing quality are possible to change along with the idle time; environmental and physical changes. First, the environmental condition, such as temperature and humidity ratio, can change during the idle period. Totsuka *et al.* [1], Sim *et al.* [2], and Li and Dianat [3] stated that the humidity ratio (HR) and temperature (Temp) are factors which causes printing variations. Although the office environments are air-conditioned, the environmental condition is not controlled exactly during the night. Thus, the variations in the HR and Temp affect the printing quality. Second, since the printer does not stay in the same physical condition during the idle time, it also contributes to cause the printing variations. However, the detailed physical changes inside the printer cannot be investigated. Thus, in this study, the physical change is not considered in the experiments.

From the points stated above, we can define idle time effect. The idle time effect is defined as color or tone variations between the prints before- and immediately after- a printer having been idle for an extended period of time. The idle time effect incorporates the color or tone variations caused by the environmental and the physical change during the idle period. Figure 1 describes the concept of the idle time effect. Although the same print-job "A" is ordered to the same EP printer, because of the idle time effects, the print-outs show tone variations.

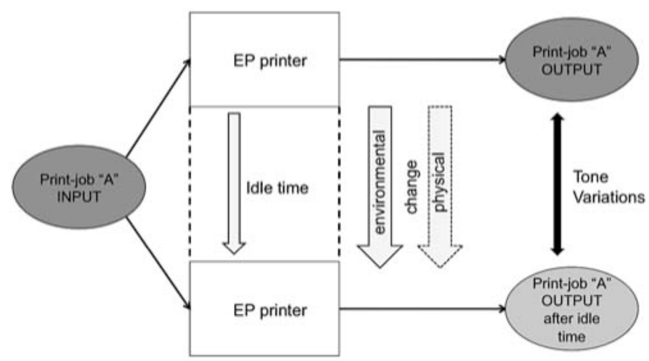

Figure 1. *Idle time effects*

This paper investigated the idle time effect. Although the idle time effect is widely experienced in the office environment, to the best of our knowledge, no prior studies have been published on this topic. As a first step to study the idle time, this work focuses on the proof of the existence of the idle time effect and statistical analysis. In the study, 15 hours of idle time, which is regularly experienced in an office setting from 5 pm to 8 am, is investigated. The study first introduces a methodology on how to design the experiments with the printer idle time; and then, the experimental results will be presented.

Design of Experiments

The preliminary experiment is required to investigate inherent printer behavior. Studying the printer behavior is useful to determine the test printing suite for the idle time experiment and to understand the level of the printer's intrinsic tone variations. For example, if the inherent tone variation is larger as the printer prints more than 50 pages continuously, then the printer, which prints more than 50 pages unceasingly, should not be used for the idle time experiment. The reason is that the idle time effect cannot be identified because of the inherent tone variations. From the preliminary experiment, appropriate number of pages for testing the idle time effect is determined. Since the goal is to identify the idle time effect, the inherent variations should be excluded before conducting the main experiment.

Figure 2 describes the experimental design of the prelimi-

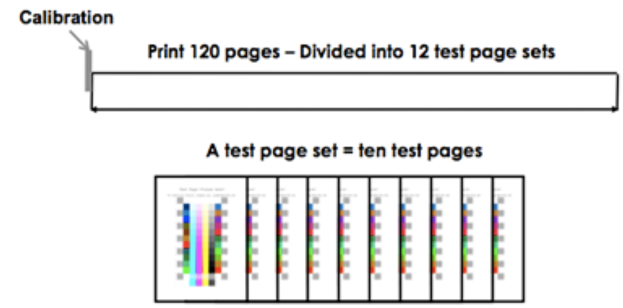

Figure 2. Experimental design for preliminary experiments

nary experiments. After an engine calibration, a printer used for this research is enforced to print the same 120 test pages continuously. The 120 test pages are divided into 12 test page sets and each set has ten identical test pages. The test page includes patches of four primary colors (CMYK) with 13 density levels in the primary colorants and 22 secondary colors. Each color patch is measured with a spectrophotometer (X-Rite DTP70); and the unit for the color or density measurement is ΔE76 from paper white. Throughout this paper, out of the various patches, only the 66.6% gray level in black is employed in the analysis.

Figure 3 describes the design of the main experiment. Following the procedures in Figure 3, one observation for the idle time effect is obtained. For these experiments, four off-the-shelf of the same model printers were placed in a temperature controlled environment. Besides the printer idle time, the temperature and the humidity ratio were also selected as the experimental factors. Throughout the procedures, temperature, humidity ratio, and cartridge page count are monitored and recorded. The detailed descriptions for each procedure follow.

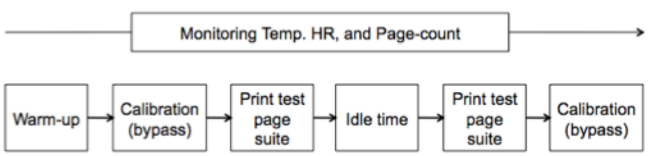

Figure 3. Experimental design for main experiments

The first procedure is the warm-up printing. A printer prints sufficient number of pages to warm-up the printer; and this number will be decided after obtaining the results of the preliminary experiments. Since the initial condition of a printer may not be the same from trial to trial, the warm-up is required to set up the initial condition as close as possible. The second and the last procedures are the calibration. The printer calibrates, but printing of the test pages bypasses the calibration effect. The third and the fifth procedures are printing phases. The test page suite will be developed based on the results of the preliminary experiments and each test page suite will be printed in each procedure. The printer is idle for 15 hours in between the printing phases.

Preliminary experiments

The preliminary experiments help to identify a sufficient number of printings for the warm-up phase and to determine the number of printings in one set of experiments. Table 1 presents the mean ΔE76 differences between two test page Sets for which the differences are statistically significant. Each column and row indicates the order of the test page Sets. That is, "2nd" means the second Set, which is 11th to 20th test pages out of 120 printings, and "8th" represents the 71st to 80th test pages. The positive (negative) value indicates the mean of the i^{th} row test page Set is larger (smaller) than the mean of the j^{th} column Set. Because of the space limitation, Table 1 doesn't show the columns numbered from "9th" to "12th". All the cells of the column from "9th" to "12th" have negative values.

Table1: Significant mean ΔE differences between the two test page Sets

Test page set	2nd	3rd	4th	5th	6th	7th	8th
1st		0.9					
2nd	N/A	0.7				-0.7	-1.0
3rd	-0.7	N/A				-1.1	-1.3
4th			N/A				-0.6
5th				N/A		-0.7	-0.9

From Table 1, it is identified that the ΔE76 values of the first 20 pages are larger than ΔE76 of 21st to 30th test pages. Also, after 61st printings, the ΔE76 gets larger which means the tone becomes darker. Hence, the first 20 pages can be said to be unstable in terms of the printing quality, while the third to sixth sets are stable. From the results, it is suggested that the warm-up needs to be at least 20 pages and the total printings in one set of experiment should be less than 60 pages.

Main experiments

In this section, we describe the main experiments for the idle time effect.

Test page suite

Figure 4. Test page suite

Figure 4 represents the test page suite. There are eight test pages and two general type of documents. With use of this test page suite, one set of experiments is composed. Following the preliminary results, two test page suites (20 pages) will be used for the printer warm-up. After a calibration, a test page suite is printed, then printer is idle. Another test page suite is printed after the idle period and the last calibration is performed. Total printings in one experiment set is 40 pages which are less than 60 as the preliminary results suggested.

Identifying the idle time effect

As a performance measure, the idle time effect is identified by the data obtained after the idle period. Figure 5 shows the performance measure. The figure is obtained from a real experiment data. First, a two sigma control limit is constructed with the eight test pages printed before the idle time. The two sigma control limit is obtained by $mean \pm 2\sigma$. Then, the test pages after the idle time which are outbound of the control limit is considered to be under the idle time effects. For example, from Figure 5, the first and the second test pages after the idle period are outbound of the control limit. Then, it is said that the idle time has impact on the first two test pages after the idle period.

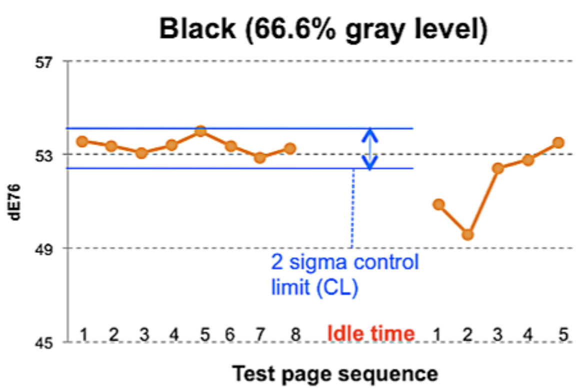

Figure 5. Identifying the idle time effect

Data acquisition

Total 39 experimental observations were acquired. There were two scenarios in the observations; 1) constant temperature during the idle time and 2) temperature change during the idle time. 17 observations were obtained from the first scenario and the other 22 observations were from the second scenario. Table 2 shows the collected data with the environmental factors. For the scenario 2, only the case of temperature drop was considered. In the experiments, cases of 5 to 9 degrees Celsius temperature drop were investigated. The level of HR encompasses typical office environment humidity level which is $9 \sim 10\ g/m^3$ and, in each experiment, the level of HR changed less than $1.0\ g/m^3$. The cartridge page-count ranges from one to 2300 which is a full range of a cartridge. The consumable such as the cartridge page-count is considered as one of the factors which affect the printing quality [1]. However, since the page-count difference in-between the idle period is just one, the cartridge page-count was not included in the experimental factors.

Table2: Data collection

Scenario	Temp. (°C)	H.R. (g/m^3)	Pgct	# of obs.
No temp. change	23 ± 1	$6 < x < 13$	1∼ 2300	17
Temp. change	30 $\pm 3 \rightarrow$ 23 ± 1	$6 < x < 13$	1∼ 2300	22

Results and Analysis

Figure 6 displays the idle time effect. The figure represents the percentage of the cases of the significant ΔE decrease/increase and no change for each test page after the idle period. The significant decrease (increase) indicates that the ΔE value of the data is smaller (larger) than the two sigma control limit. The ‘no change’ means that the data is inbound the control limit. For example, in the first scenario, up to 90% of the first test page after the idle period out of 17 observations shows smaller ΔE than the control limit. Similarly, in the second scenario, around 70% of the fifth test page after the idle time out of 22 observations are inside the control limit.

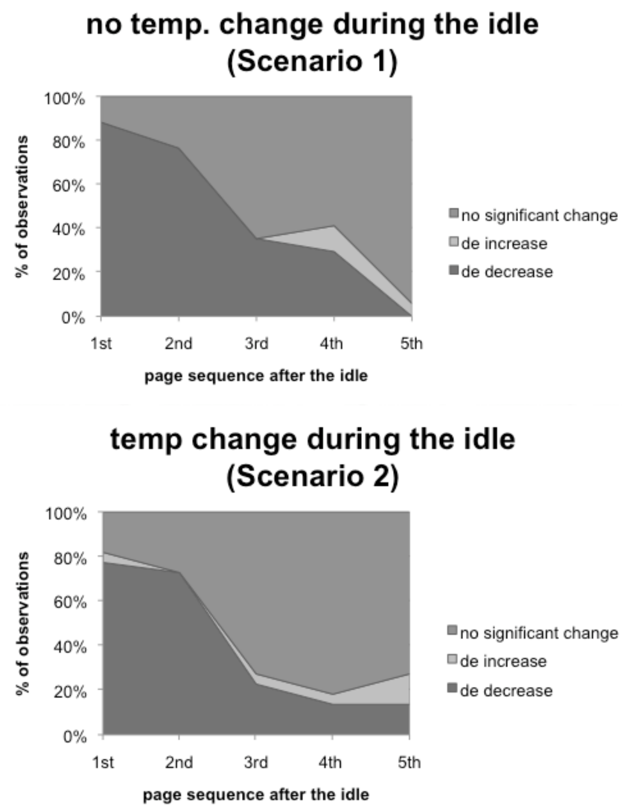

Figure 6. Idle time effect against sequence of the test pages printed after the idle period

From Figure 6, the idle time affects on the first page after the idle period more than 75% in both scenarios as a whole. The effect lasts similarly up to the second test page, but the effect reduces drastically from the third test page. At the fifth test page, more than 70% observations are inbound the control limit. That is, the idle time effect hardly reaches to the fifth page.

The printer behavior to recover from the idle time effect is analyzed. It is defined that the printer is in transient state while it is recovering to the normal state which is the ΔE values of the test pages are inside the control limit. In every idle time experiment, the number of test pages after the idle time, which is outbound of the control limit, is counted and the mean number is calculated. Table 3 presents the mean numbers in both scenarios. As shown in Table 3, the printers recover from the idle time in two to three pages after the idle period. This result is compatible with Figure 6. The mean numbers of printings in transient state of both the first and the second scenarios are similar. That is, it is hardly to be said that the temperature change during the idle period do not make any difference on the printer behavior in transient state.

Finally, it is questionable how much ΔE variation is expected

Table3: Transient behavior of the printer from the idle time effect

Scenario	Mean # of pages printed before recovering
Temp. change	2.59
No temp. change	2.53
Total	2.56

in the first or the second test page after the 15 hours of idle time. Equation 1 defines the ΔE variation after a printer being idle. With the calculated ΔE variation in each observation, the expected ΔE variation is procured. Table 4 presents the expected ΔE variations of the first and the second test page after the idle time.

$$\Delta\text{E variation} = \frac{\sum_{i=1}^{8} \Delta E_i}{8} - \Delta E_{j^{th}\ page\ after\ the\ idle\ time} \quad (1)$$

Table4: Expected ΔE variations in the first and the second test page after the idle time

Page	No. Temp. change	Temp. change	Total
1st	2.27 ΔE	2.20 ΔE	2.24 ΔE
2nd	2.32 ΔE	2.67 ΔE	2.50 ΔE

Since the positive value means that the ΔE decreases after the idle time, from Table 4, note that the expected ΔE decreases in the second page is larger than the first test page. Again, the temperature change doesn't affect the patterns of the ΔE decreases. In sum with Figure 6, although the cases of showing ΔE decreases, for the second test page, are less than the first test page, the amount of the decreases is larger.

Conclusion

After the electrophotographic (EP) printer having been idle for an extended period of time, it is observed that there is tone variation in the prints immediately after the idle period. This study defines the idle time effect as color or tone variations between the prints before- and immediately after- a printer having been idle. In this study, 15 hours of idle time was investigated. The idle time effect was analyzed with four off-the-shelf printers of the same model. All the printers were placed in a temperature controlled environments with their engine calibration disabled. From the analysis, it was shown that the idle time effect makes the tone lighter significantly. In the sense of the number of cases which show the significant tone variations, the idle time effect is being debilitated as the printer prints and it diminishes once three pages have been printed after the idle time ends. Meanwhile, in the sense of the amount of the tone variations, the second pages after the idle time shows larger tone variations than the first pages. The experiments was conducted in two scenarios; one was with no temperature changes during the idle period and the other was with five to nine degrees Celcius temperature drop. The two scenarios perform similarly in all the analysis, thus, it is stated that the temperature change does not affect the idle time effect.

Acknowledgments

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Author Biography

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