Advanced Computer-controlled Instrumentation for Electrophotography

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Abstract

The ultimate objective in digital printing is to deliver printed output that satisfies customer requirements and expectations. To achieve this objective, we must be able to control the many factors that affect print quality. This in turn requires that we be able to understand and quantify these factors. If we can do this, we can make print quality predictable. In this paper, we will describe a family of advanced computer-controlled test instruments for electrophotography that analyze these critical factors. The systems discussed evaluate photoconductors, charge rollers, development rollers, transfer rollers, fuser rollers, and toner fusing. In addition, we discuss an automated print quality analysis system that quantifies output of any printing technology. These instruments use state-of-the-art control software and integrate many functions and innovative features to test for reliability, life assessment, and reusability. We will discuss their principles of operation, design requirements, implementation, and applications. These systems are used in R&D, production quality control, and component recycling applications.

Introduction

The complexity of the digital printing process has historically made predicting print quality quite difficult, and evaluation methods (e.g., for interpreting print tests) have often been subjective and operator-dependent. However, in recent years computerized quality control test systems have become available for performing quantitative evaluations of printer components, sub-systems, and print and color quality. In the past, most computerized QC test systems were proprietary systems developed by manufacturers or research labs for very specific applications. Now, the widespread use of personal computers and the availability of advanced software and software development tools have made possible the development of standardized, commercially available QC test instruments for users representing all aspects of digital printing. A growing array of such instruments provides a common language for communication within the industry and frees up resources previously invested in non-standard in-house designs. By using state-of-the-art test systems to analyze the variables contributing to print quality, we can gain the insight needed for real advances in print quality control. Advanced software has made it possible to shorten test cycles, making computerized QC instrumentation practical and efficient for both production and laboratory environments. Besides quantifying present quality and condition, automated QC test systems make it possible to predict future outcomes. This can only be achieved if tools are available that make possible the collection of large enough quantities of performance data for statistically significant results.

The ultimate quality of a print depends on many variables. This paper focuses on factors relating specifically to electrophotographic printer technology – in particular, the following printer subsystems:

- Charging subsystem
- Exposure subsystem
- Development subsystem
- Transfer subsystem
- Fusing subsystem
- Cleaning subsystem

Figure 1 below illustrates the relationships of these subsystems.

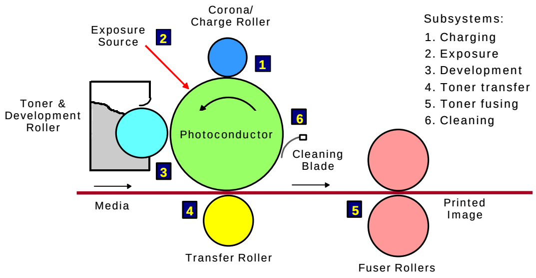

Figure 1 Major Printer Subsystems

The behavior and interactions of the components in the printer subsystems are key determinants of dot, line, and large area image attributes, the building blocks of print quality. Test systems for printer components and subsystems, therefore, will illustrate how computerized instrumentation can be applied to print quality control.

Instrumentation for evaluating printer components

The instruments discussed in this section include test systems for photoreceptors, charge rollers, magnetic rollers, transfer rollers, and fuser rollers. The inspection techniques used are non-destructive and non-contact, allowing the systems to be used for both incoming and outgoing quality control in production environments, as well as for product development and scientific research. The systems perform rapid, high-resolution scans of finished components or components at various stages of production, delivering detailed characterizations without special specimen preparation.

The measurement principle used in these instruments is electrostatic charge decay (ECD)[1]. The components discussed here consist of a substrate or a metal shaft coated with a layer of semi-insulative or photoconductive material. This structure lends itself well to the ECD technique[2-4]. With this technique, an electric charge is deposited on the surface of the sample, and the leakage of the charge through the thickness of the coating is monitored by measuring surface potential using a non-contact electrostatic voltmeter. The rate of surface potential decay is a direct measure of the dielectric and photoelectric properties of the coating, important contributors to print quality.

The ECD technique and advances in computer-controlled scanner technology have made possible an innovative feature of these systems — electrostatic mapping[2,6]. This technique simulates the electrophotographic printing process and is designed to measure specifically those defects that affect print quality. By mapping charge and discharge uniformity over the surface of the component, coating uniformity is revealed. Mapping can also be used for measuring physical wear patterns and estimating remaining coating thickness. It is thus a powerful tool for testing the durability and assessing the life expectancy of components[5]. Mapping can also be used to detect coating defects such as pinholes, scratches, and contamination. It can be used to evaluate not only individual components but also component interactions, e.g., charge roller/photoconductor interactions as they affect charging uniformity[6].

Instrumentation for evaluating photoreceptors

Photoreceptor design covers a wide range of materials and geometries, encompassing various organic and inorganic compositions and various geometries including drums and belts. A typical organic photoreceptor (OPC) drum, for example, consists of an aluminum substrate with a multi-layered photoconductive coating containing charge transport, charge generation and charge blocking layers. In the printer, the drum is uniformly charged and selectively exposed to produce an electrostatic "image." The toner is then drawn selectively onto the photoreceptor – onto discharge areas in a discharge area development (DAD) system or charge areas in a charge area development (CAD) system.

Defects in the electrophotographic behavior of the photoconductor are predictive of defects in print quality. For example, in DAD systems, if the charge acceptance level in the photoconductive coating is too low or if dark decay is excessive, the result will be toner background on the final print. If the discharge voltage is too low, excessive toner will be attracted to the drum, reducing page yield. If, on the other hand, the discharge voltage is too high, optical density on the print will be reduced, and the resulting residual voltage will cause ghosting. Cyclic fatigue is another factor affecting print quality. Over time, fatigue degrades the OPC's ability to charge and discharge properly, resulting in degradation of print quality. Clearly the electrophotographic behavior of the photoconductor is critical.

In a typical photoreceptor test system, the photoreceptor is charged with either a corona-type charger or a charge roller, depending on the application. The choice of exposure source depends on the types of analyses to be performed. To closely simulate the printer environment, a scanning laser or LED array is preferred. However, for maximum flexibility, a tungsten halogen source with a selectable interference filter makes it easy to change the exposure wavelength for characterizing the photoreceptor's spectral sensitivity. Erasure is either by a bank of LEDs or by charge roller. The scan parameters, including charging voltage, exposure energy, erase intensity, scan type, scan path, and scanning speed, are user-controlled. Test functions include charge acceptance, photo-discharge, dark decay, cyclic fatigue, photo-induced discharge curve, time of flight, and capacitance measurements. Pass/fail criteria are user-specified. Implementation of this evaluation methodology for photoreceptors is shown in Figure 2.

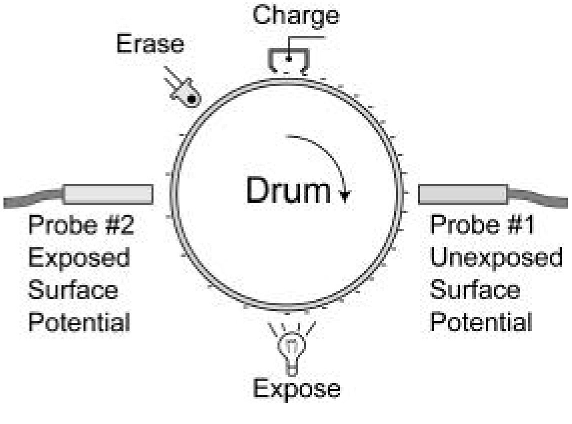

Figure 2 Photoreceptor Test System: Measurement Principle

As noted, the mapping feature is an important diagnostic tool, both for assessing electrophotographic uniformity and for detecting physical defects such as pinholes, scratches, and contamination. For mapping the drum surface, a two-dimensional scanning capability is required. Typically during the scan, one axis (the indexing axis) is stationary while the other (the scanning axis) moves. When the scanning axis reaches the end of one cycle of motion, the indexing axis advances one step. The process is repeated until the entire photoconductor surface has been measured. Several representative scanning geometries, applicable to drums and other components, are shown in Figure 3.

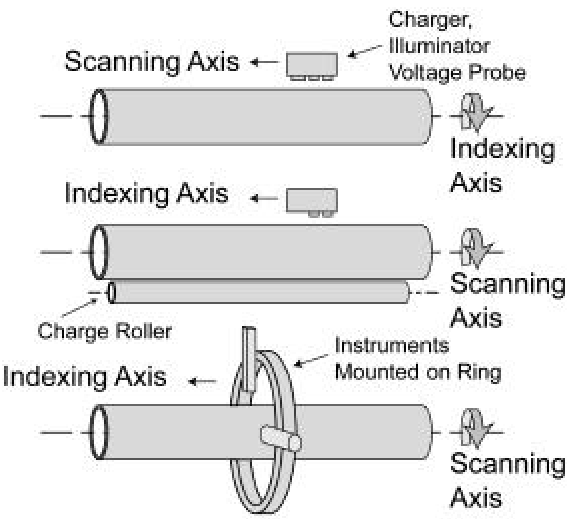

Figure 3 Some two-dimensional scanning geometries

Discharge: OPC A

Discharge: OPC B

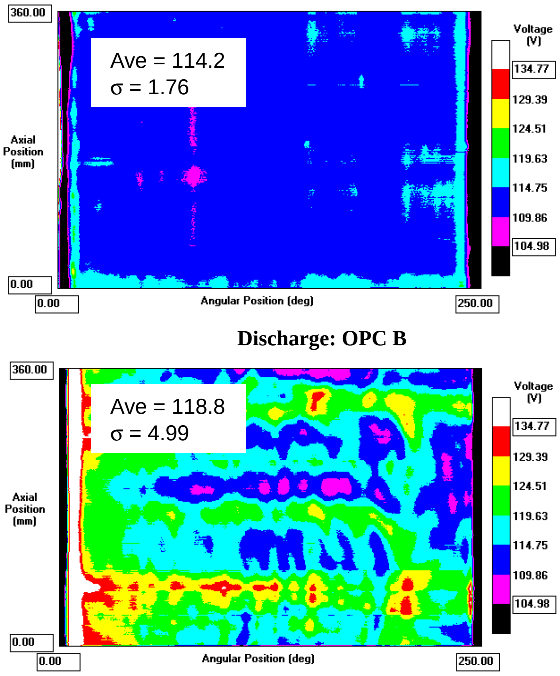

Figure 4 Photoconductor discharge uniformity mapping (Ave = average of entire voltage map; σ = standard deviation of entire voltage map)

Figures 4 and 5 show sample output of a test system of this kind. Figure 4 shows discharge uniformity maps for two OPCs. As shown, OPC A is much more uniform than OPC B. This is clearly indicated by the standard deviations. The optical density of prints produced with OPC A will consequently be more uniform than those produced with OPC B, a result confirmed in print testing[6].

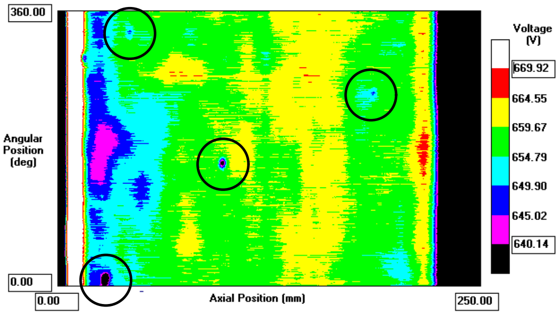

Figure 5 Charge Acceptance: Used OPC, with defects highlighted

Figure 5 shows a charge acceptance map of an OPC with four pronounced defects (circled). Using standard electrostatic voltmeters, pinholes as small as 50-100 µm can readily be detected. Since electrostatic mapping is a direct measure of the charging and discharging behavior of the component, defects seen on an electrostatic map are very likely to produce defects on the print. In laboratory testing, the defects highlighted in Figure 5 did in fact result in print defects[6]. (It should be noted that detecting defects is much easier than characterizing them, although there is a clear relationship between defect size and voltage depth.)

In addition to the test systems described above, a coating thickness gauge based on the eddy current principle offers a reliable method of photoconductor evaluation for production environments. The eddy current technique produces reliable results only if the system has a drum support fixture of sturdy design. An available system that meets this requirement gives very reliable thickness measurements in the range specified, achieving better than 0.3µm precision.

Instrumentation for evaluating charge rollers, magnetic rollers, transfer rollers, and fuser rollers

A typical charge roller consists of a metal shaft with a molded elastomer layer and polymer surface coatings. The dielectric properties of the elastomer and the coating can critically affect the charging uniformity of the photoreceptor. Faulty charge roller charging may undercharge the photoreceptor, resulting in toner background and ghosting.

A typical magnetic roller consists of an aluminum sleeve with a thin layer of oxide or a semi-insulative polymer coating. The dielectric properties of the surface layer on the magnetic roller sleeve are critical to the development process. A surface layer with a low charge relaxation rate, for example, may lead to unwanted residual toner on the roller between prints, resulting in ghosting or low print density.

A typical transfer roller consists of a metal shaft with a molded conductive elastomer or elastomeric foam layer. Faulty transfer roller charging can affect the efficiency and uniformity of toner transfer from the photoreceptor onto the print media. This results in low or non-uniform print density and poor edge quality in lines and solid areas.

A typical fuser roll consists of a coated shell with a heating element inside. The dielectric, thermal, and adhesive properties of the fuser roller coating are critical to the fusing process.

The same ECD measurement principle can be used for charge rollers, magnetic rollers, transfer rollers, and fuser rollers, as shown in Figure 6[2-4.] As with photoreceptors, two-dimensional scanning allows for evaluation of the entire surface of the roller. Wear and physical defects that lead to print defects can also be examined. The roller is charged with a corona-type charger, and the surface potential is measured. Test functions include charge acceptance, accumulation, dissipation, and charge decay scans. Scan parameters, including charging level, scan type, scan path, scanning speed, and pass/fail criteria, are user-specified.

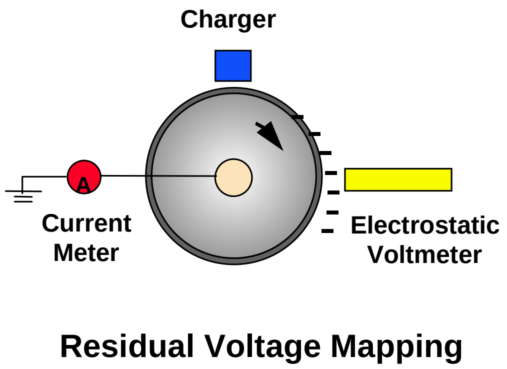

Figure 6 Charge Roller, Magnetic Roller, Transfer Roller, and Fuser Roller Test System: Measurement Principle

Some representative test results for charge rollers and magnetic rollers are shown below. Figure 7a shows the correlation between the residual voltage on the charge roller, measured using the ECD technique, and the voltage developed on the OPC. (OPC measurements were made using an instrumented cartridge method[11].) In essence, high residual voltage on the charge roller is indicative of slow dielectric relaxation and inefficiency in charging the OPC. This leads to low OPC charge voltage, producing toner background in the print, as illustrated in Figure 7b.

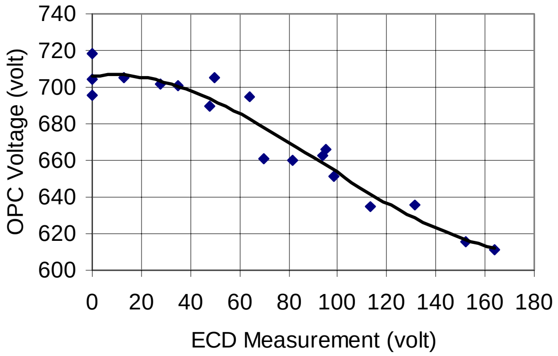

Figure 7a Correlation between high residual voltage on charge roller (ECD measurement) and voltage developed on the OPC

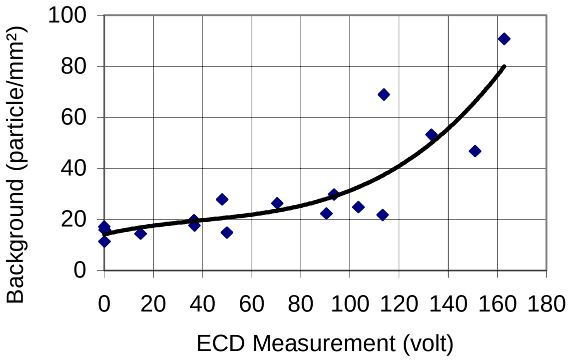

Figure 7b Correlation between high residual voltage on charge roller (ECD measurement) and background on print

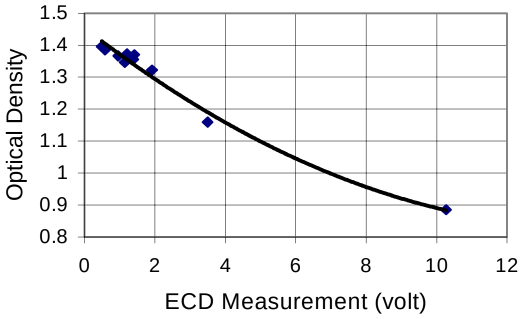

Figure8a Correlation between residual voltage on magnetic roller (ECD measurement) and optical density

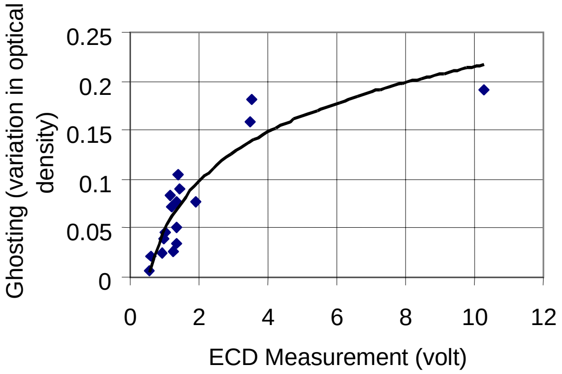

Figure 8b Correlation between residual voltage on magnetic roller (ECD measurement) and ghosting

Figures 8a and 8b show similar correlations between ECD residual voltage on mag rollers and print quality as it relates to optical density and ghosting. As with charge rollers, slow dielectric relaxation on the mag roller is a leading cause of print quality degradation.

Instrumentation for evaluating toner fusing

In dry toner electrophotography, the technology most commonly used to fix the toner to the media is hot-roll fusing. This is a complex process in which the toner melts, coalesces, spreads, penetrates into the fibrous structure of the paper, and resolidifies under the combined influences of time, temperature, and pressure. The success of the process depends not only on the melting and viscous flow characteristics of the toner, but also on a wide range of variables such as machine design, roller design, roller lubrication, toner composition, and media characteristics. Thus, the ability to quantify toner fusing is critical for developers of toners, resins, media, fuser rollers, fusing subsystems, and related products.

A fundamental objective in the development of hot-roll fusing sub-systems is to optimize fusing latitude. The fusing latitude, or “fusing window,” is bounded below by cold offset due to adhesive failure between the toner and the media, manifested by the transfer of unfused toner to the hot roll. It is bounded above by hot offset due to cohesive failure within the molten toner layer, manifested by adhesion of the toner to the hot-roll surface. Fusing latitude is illustrated in Figure 9.

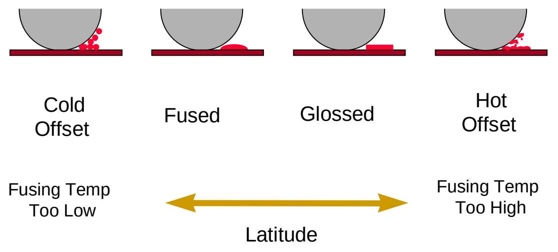

Figure 9 Fusing latitude in hot-roll fusing

Maximizing fusing latitude is essential to ensure that acceptable fixing can be achieved consistently despite uncontrollable disturbances in a real-world printing environment. The recent introduction of a stand-alone computer-controlled fusing test apparatus makes available a highly flexible tool for characterizing and optimizing the hot-roll fusing process[7,8]. With this apparatus, researchers’ efforts can now focus on experiment design and analysis of the results, freeing up time previously spent setting up equipment and gathering and managing large volumes of test data. A schematic of the fusing system is shown in Figure 10.

The test apparatus closely simulates the operating environment of a printer but allows the user to vary each of the process conditions independently. It thus becomes possible to determine the fusing latitude of a given toner under different conditions (e.g., different roller temperatures, contact pressures, process speeds, roller lubrication, roller types or media types) or the range of a process variable within which fusing quality is acceptable for a particular application.

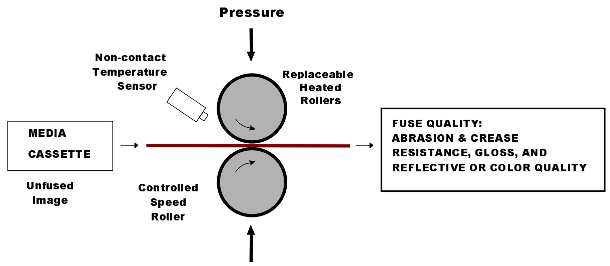

Figure 10 Toner fusing test system

Experiments performed with the fusing apparatus and some simple techniques for evaluating fusing quality exposed clear differences in fixing quality among several toners[7]. Fixing quality, computed as “fixing ratio,” is a measure of the adhesion of the toner to the media[8]. Using the same rollers, roller pressure, process speed, and lubrication throughout while varying the fusing temperature, we could easily demonstrate the fusing latitudes of these toners on both paper and transparencies. Figure 11 shows a typical fusing latitude curve[8].

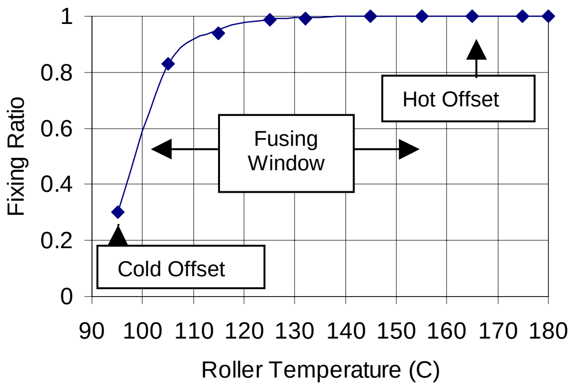

Figure 11 Fixing quality as a function of fusing roller temperature

In another series of experiments, we quantified the influence of media thickness on fusing quality. In particular, our studies showed the importance of thermal diffusivity (the ratio of thermal conductivity to specific heat) of the media in hot-roll fusing. When the thermal diffusivity of a given media is known, a characteristic time constant for heat transfer can be computed for its thickness. As total media thickness increases, the thermal diffusion time constant increases, reducing the heat energy available for fusing. Thus, the thermal diffusion time constant is another tool for understanding and predicting fusing quality[8].

The same fusing apparatus can be used to examine the mechanisms of gloss development or to study the roles of lubrication, fuser roller design, or any of a host of other variables.

Instrumentation for evaluating print and color quality

The methods described above are designed to evaluate printer components or subsystems. However, another important subject for computerized QC is the printed output of these components and subsystems. Print quality evaluation has historically been subjective, operator-dependent and unreliable. An automated print quality analysis system now available uses a computerized machine vision system with a comprehensive array of built-in measurement tools to quantify the fundamental image elements (dots, lines, and solid areas) and their quality attributes (dot gain, line width, sharpness, edge roughness, optical density, contrast, modulation, image noise, tone reproduction, color, and other characteristics)[9,10]. Key components of the system include a computer-controlled x-y positioning stage, a CCD camera, high-resolution optics, a light source and a computer that runs the control software. Figure 12 shows the system architecture.

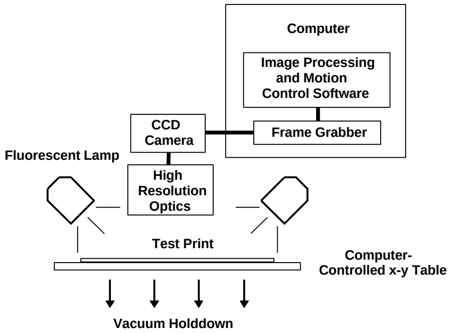

Figure 12 Print Quality Analysis System Architecture

Using specially-designed test targets, the system executes user-selected test sequences specifying the regions of interest, the sequences of measurements to be made, and the analyses to be performed. Scan data are reported automatically. Important attributes of the system are fast data acquisition, objective and reliable measurements, and sophisticated analysis and reporting features. The system analyzes printed output on any media. A computer-controlled spectrophotometer is integrated into the system but can also be used as an independent test system for color studies.

Summary

In this paper, we introduce a family of advanced computer-controlled test instruments for characterizing the critical components in the electrophotographic printing process. The characteristics of these components determine print quality. This family of instruments make it possible to amass very large amounts of data for statistically reliable studies for both laboratory and production use. Given their availability, standardization, flexibility, speed, and computing power, these instruments now serve as tools for communication for users throughout the digital printing industry.

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