Metrology of Small Scale Features in Electrophotographic Non-Image Areas as Forensic Evidence

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Abstract

The forensic community has traditionally relied on the qualitative examination of large-scale features for the identification of the electrophotographic device which produced a document. When no such large-scale features are present on a document, identification of the electrophotographic device which produced it is not usually possible. The following is a qualitative description of a proposed feasibility study to determine whether or not the small-scale features in non-image areas can be quantified for identification purposes.

Introduction

The forensic document examiner is responsible for conducting forensic analysis of documents to determine a document's: origin, history, authenticity, manner or method of preparation, and latent evidence such as indented handwritten impressions. Examinations include the comparison of handwriting, typewriters or typewritten characters, impact printers and their output, commercial printing processes (for example lithographic offset, letterpress, gravure), security printing processes, and electrophotographic devices and their output. Such examinations are conducted using a variety of means and equipment including: visual examination, optical microscopes, imaging systems, latent indentation development equipment, radiography, and metrology equipment.[1-3] The evidence found from such examinations is considered and through scientific reasoning a conclusion reached as to the sequence of events pertaining to a document's preparation and history. As with any forensic science there are limitations in what can be determined from the evidence. There are situations where an inconclusive opinion is rendered either from a lack of data for a particular examination or from fundamental limitations in our knowledge and understanding of a physical phenomena.

Forensic Terminology

The forensic document examiner uses the terminology "class characteristic" to describe those characteristics that are common to a group of entities. For example, documents prepared by successive printers from an assembly line will have common toner characteristics (for example, dual component dry toner), fusing technology (for example, hot roll fused), and print resolution or paper size capabilities. These documents would have the same class characteristics. Other documents produced on another printer using liquid toner would have different class characteristics. Documents having different class characteristics could not have been produced by a common printer. Some class characteristics are quite distinct and are easier to determine than others. The example of the liquid and dry toner is one such example. Quite often it is not easy to distinguish between the class characteristics of the electrophotographic process when the technology used is similar. This is especially the case when no suspect printers are part of the evidence; and when no destructive testing of the documents is permitted.[4,5]

"Individual characteristics" are those features which are unique to a specific entity. In theory, every printer will have unique characteristics which will manifest themselves in the printed output. With the improvements in electrophotography the individual characteristics are more subtle and difficult to detect when compared to early electrophotographic devices. The individual characteristics do vary over time, this fact plays an important role in the identification process.

The other terminology used by forensic document examiners are "known documents" (sometimes referred to as "specimen documents") and "questioned documents". Known documents are those whose origin and manner of preparation is established. For example, photocopies originating from a specific photocopier at a specific date and time. Questioned documents are documents which have one or more facets about them that are in question.

Identification of Electrophotographic Devices

Distinguishing between documents that were produced using different technologies can normally be achieved by visual inspection under low magnification. For example, documents produced by an ink-jet process versus electrophotography versus thermal printers are easily distinguishable. Further class characteristic distinctions within one technology may also be disclosed upon examination. Chemical analysis of the toners has had some limited application and success in the distinction of class characteristics.6,7 Even when such testing may disclose evidence, the usage of destructive testing is not permitted in some instances.

Individual characteristics that are currently used for forensic identification are the large-scale features on documents. For example, large-scale features (noise) on photocopied documents originating from sources such as: scratches on the copy platen, and dust contamination on the platen or on the lid covering the document. These large-scale features are the noise which is visible as spatially static or spatially periodic on the document. Spatially static noise will appear at the same position for each document produced at approximately the same time, refer to figure 1 for an illustration of spatially static noise. Spatially static noise will change over a period of time as the device is subject to more wear or is serviced with repaired parts. Maintenance records will indicate what parts on a electrophotographic device were changed or cleaned. This information may indicate when the spatially static noise pattern changed. Some spatially static noise may change from user serviceable parts, for example cleaning of the copy platen.

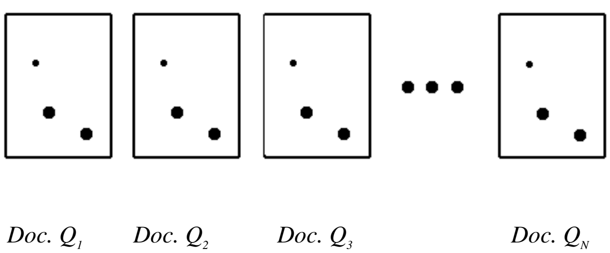

Figure 1. Illustration of Spatially Static Noise

Spatially periodic noise results from causes such as: damage to the fusing roller, non-uniform properties of the photoconductor,8 and improper cleaning of the photoconductor between cycles. This periodic noise will appear at intervals which are dependent on the circumference of the non-ideal electrophotographic component(s). The spatially periodic noise is time dependent and is a function of the further degradation of the electrophotographic components when no servicing or parts are changed. Parts which are not user serviceable and require servicing calls which are documented do have reliable time references. The pattern of spatially periodic noise may be different after servicing. In recent years more electrophotographic devices utilize cartridge systems containing toner and a new or recycled photoconductor. These cartridges are installed by the end user, such cartridge changes are often not documented. Replacement of the cartridge changes the individual characteristics of the electrophotographic device. Refer to Figure 2 for an illustration of periodic noise on three successive documents from the same electrophotographic device. Note the vertical distance between each arrow is $2\pi r$, where r is the radius of the defective electrophotographic component responsible for the noise.

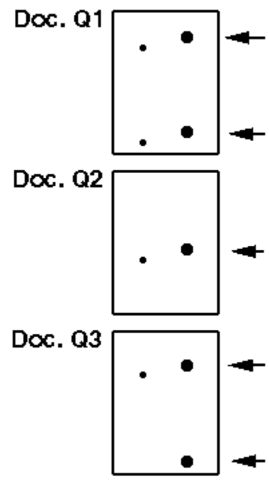

Figure 2. Illustration of Spatially Periodic Noise

Whether the noise is spatially static or periodic, only the large-scale noise of order mm or sub-mm scale is normally considered by the forensic community. For example, damage to the fusing rollers9 (spatially periodic) or damage/contamination to the copy platen. In order to identify an electrophotographic device as having produced the questioned documents there must be a strong correlation between the class characteristics and individual characteristics.

When cases are submitted to the laboratory the evidence submitted consists primarily of documents, sometimes suspect electrophotographic devices are submitted, where one or more questions of the type listed below may be posed:

1) Were the documents produced on the same electrophotographic device? Consideration has to be made whether an original laser printer printed document was subsequently copied.
2) If the documents were produced on the same electrophotographic device, were the documents produced at approximately the same time? Conclusive answers are usually only possible when large scale noise is present on the document.

3) Are the documents submitted multi-generation copies of one another? This question will often arise when allegations of alterations or obliterations to a document are made.

Metrology of Features

Improvements in electrophotographic technology have made the reliance on large-scale defects for identification a limiting endeavor. Forensic document examiners can manually measure selected features on documents for comparison purposes. This procedure is limited for a number of reasons. First, only linear types of measurements can usually be made this way with high precision ruling glass slides or similar metrology test targets. Measurements such as area, raggedness, major-minor axis lengths, satellites, void areas in solid development, and angular measurements are difficult to conduct through a manual process. The difficulty lies not only in the number of data points to be collected but in the lack of repeatability for such manual measurements.

A solution to this problem can be found in machine vision systems which utilize high quality low aberration optics, CCD cameras, calibrated motion stages, optical reference targets, and a computer for orchestrating all the movements, image capture, metrology, data handling, and data processing. Utilizing automated image quality test equipment allows repeatable automated measurements to be made of features on documents that may be of identification value.

In this proposed feasibility study, the first step will be the metrology of large-scale features that are currently used for identification. This will quantify a process which is currently quasi-quantified by manual measurements and optical overlays. Examination of this data should allow for the identification of an electrophotographic device having the same large-scale features on several questioned documents.

The second step will be the metrology and analysis of the small-scale features such as background development, and the toner satellite noise10 surrounding image areas. Complicating this analysis is the fact that the cause(s) of such small-scale features are not always well known. For example, background development can be caused by; overbiasing the development electrode11 and wrong sign toner12. One way of quantifying the background development can be made using a modified Dooley-Shaw-Edinger metric:

$$GS = \sqrt{C(d_1^4+d_2^4+d_3^4+\ldots+d_n^4)} \qquad (1)$$

Where C = 4.74 x 10-6, a dimensionless constant, dn is the effective diameter (μm) of each background toner spot in a 1 mm2 area13,14. The difficulty in measuring background development is one of optical resolution of the small toner spots. Although the location of each toner spot on a document may not be attributed to a specific defect on an electrophotographic component, measurement of the background development in selected areas of the document may disclose important evidence. Measurements of the toner satellite noise may disclose evidence such as the extent of toner surface treatment. Recent research suggests that greater surface treatment of toner tends to increase the tendency for toner satellites10. The examination of the data and understanding of the theory of the electrophotographic process will be essential in the determination of whether or not identification can be realized based on the quantification of small-scale noise. As forensic evidence, the principle of identification is that no other electrophotographic device by random chance would produce documents having identical noise features. Identification is not necessarily absolute, qualified opinions can be stated for situations where the evidence suggests that the questioned document(s) were or were not produced on a specific electrophotographic device.

Conclusion

The forensic community has had limited success in the identification of electrophotographic devices not having large-scale features. The intent of this feasibility study is to gain insight on the possible sources of subtle evidence from electrophotographic devices.

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Biography

Tobin Tanaka received a B.Sc. degree in Physics (1990) and a Diploma in Meteorology (1992) from the University of British Columbia, Vancouver, BC. From 1993 to 2000 he was employed as a forensic document examiner at the Solicitor General of Canada, Ottawa, Ontario. Since 2000 he has been a Forensic Document Examiner at the Canada Customs & Revenue Agency. His interests include the development of further techniques for the identification of electrophotographic and inkjet documents. He is a member of the IS&T and the Document Section of the Canadian Society of Forensic Science.