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Research Article

HYPER SPECTRAL IMAGING FOR DISCRIMINATION OF INKJET AND LASER PRINTERS FOR FORENSIC DOCUMENT EXAMINATION

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ABSTRACT

In modern offices, photocopies and printers (inkjet and laser) occupy a paramount part of routine work, withal making them vulnerably susceptible implement in document forgeries. Researchers had reported examination of printed toner and printers in different aspects of document frauds and instrumental methods. Albeit spectral data bases is engendered for discrimination of photocopy and printer toner there is a desideratum for application of HSI for inkjet and laser printers examination and their differentiation in dynamic system. Here in this study an endeavor is made to differentiate laser and inkjet printer strokes on paper surface by utilizing hyper spectral imaging technique for forensic document examination purport. The method can be utilized for detection of print forgeries, alterations and page supersession of printed queried documents as well as for the analysis of printers. Perhaps the most paramount distinction among inkjet and laser printers is their printing process and ingredients.

INTRODUCTION

Inkjet and laser printers

In cases like counterfeiting currency, creating forged documents, illegitimate business transactions and terrorism related criminal activities inkjet and laser printers are being increasingly used. In such activities identification of the printing process is a major question to be answered and hence is extensively used in the field of document examination. Printing inks generally consist of pigments, resins, solvents and additives whereas, inkjet printers use cartridges of liquid acidic dyes of four different colors to form other colors, laser printers use toners of liquid or dry resinous ink particles (mm range) [1].

As far as analysis is concerned both destructive and non-destructive analytical methods have been reported for examination of inkjet and laser printer inks. Inkjet printers are now moving largely toward the use of pigments as colorants; their insolubility makes analysis by simpler methods such as thin-layer chromatography no longer an option [2]. The non-destructive method includes digital image analysis system intended to detect imperceptible fraudulent alterations to digital print samples [3] that incorporated a high-resolution low noise charged couple device (CCD) monochrome camera with an optical system to enlarge images was used to obtain measurements of the relative optical reflectivity and sharpness characteristics of printed image area. Laser desorption mass spectrometry (LDMS) has been demonstrated as a powerful tool for colorant analysis [2] Raman spectroscopy and LDMS [4] have been demonstrated as effective tools for dyes and pigments analysis, which are ink components, the study was aimed to evaluate the aforementioned techniques for inkjet inks analysis in terms of discriminating power, information quality and nondestructive capability. But the gloss optimizers that coat pigment particles in inkjet inks, may prohibit colorant analysis by LDMS.

Laser-based methods and Scanning Electron Microscopy-Energy Dispersive X-Ray Spectroscopy (SEM-EDS) methods were developed [5], optimized and validated for the forensic analysis of more complex inks such as toners and inkjet, to determine if their elemental composition can differentiate documents printed from different sources and to associate documents that originated from the same printing source. Some of the nondestructive and non-analytical techniques such as image processing techniques [6] propose its use in identifying the printing process (photocopiers, inkjet and laser printers) used to generate a document. HSV color space and, in particular, hue images at high-resolution, distribution of isolated spots in the vicinity of hue edge pixels and periodicities in edge intensity profiles distinguish between the different printing processes. Image processing tools are also used for differentiating inkjet and laser printers. The Adds White Gaussian noise (AWGN) and impulsive noise energies are isolated by wavelet transformation (WT) and singular value decomposition (SVD) on the character image [7] and another was "letter" in a document which is classified using a support

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vector machine [8] that has been trained to distinguish laser from inkjet printouts.

Chemical characterization of Printing Inks using DART-Q-TOF-MS and Attenuated Total Reflectance (ATR) FTIR [9] were used to analyze inkjets, toners, offset, and intaglio printing ink. This allows for both discrimination of inks originating from different sources and the association of inks originating from the same source.

In destructive methods employed for analysis of inkjet and laser printers most of them are based on component analysis. For instance, ICP-TOF-MS (inductively coupled plasma time-of-flight mass spectrometry) with laser ablation (LA) was used to analyze photocopy and printer toners [10], isotopic analysis of black and colored toners allows identification and discrimination of covering materials from different producers, micellar electrophoretic capillary chromatography (MECC) [10] has been developed and applied to the analysis of color inkjet inks extracted from paper for forensic purposes. By comparison of recorded UV–Vis spectra, the identification of main dyes was also achievable. Effective differentiation of individual inks was possible in terms of migration time, order and specific shapes of characteristic peaks. A study by Beata M. Trzcińska in 2006 [11] differentiated between black powder toners used in laser printers and copiers through Fourier transform infrared spectrometry (FT-IR) and energy-dispersive X-ray fluorescence spectrometry (XRF). Through the results gave good discrimination (82.5% FT-IR, 90.8% XRF and 95.8% with combined) within toners and copiers and results obtained confirm the multiplicity and compatibility of toners, it was stated that not all the samples were original. XRF showed promising discriminating results even in toners with almost similar compositions but sample preparation and extraction of toner from paper surface limits its application making it a less popular method in forensic document examination.

ICP-TOF-MS with laser ablation (LA) [12] along with chemo metric methods like cluster analysis (CA) and principal component analysis (PCA) is reported in which isotopic analysis of black and colored toners allows identification and discrimination of covering materials from different producers.

Diamond cell Fourier transform infrared (FTIR) spectroscopy [13] a nondestructive technique allowed the forensic analysis of the questioned documents while preserving their integrity. Though FTIR-ATR is a better choice for forensic document examiners, its result interpretation and sensitivity always pose challenges. Most of the conventional approaches are based on destructive sampling where methods commonly used require removal of ink samples from paper by various techniques. So there is always a search on for effective and discriminative non-destructive analytical methods for questioned document examination.

Another non-destructive technique reported by Savioli *et al*. [14] involves the use of Raman spectroscopy and SERS to examine different black and colored inks printed by different inkjet and laser printers however, in this no significant differences for SERS over RS for both types of printers were observed low sensitivity and intense fluorescence signals are some of the drawback of this method [15].

Hyper Spectral Imaging (HSI)

Hyper Spectral Imaging (HSI) has always motivated forensic examiners as a choice of tool to analyze trace evidences as it is non-destructive, non-contact, non-invasive, portable and fast image acquisition system. HSI is an advanced version of spectroscopic analysis as it combines spectroscopic information with the spatial information of the samples. HSI opens a new paradigm for detection, visualization, identification and age estimation of forensic evidences. Researchers had put usefulness of hyper spectral imaging and image analysis techniques to practical use in forensic analysis. Application of HSI in treated and non-treated finger marks has been reported for chemical analysis, enhancement and imaging of latent prints from various surfaces [16] - [24]. It is applied for other areas of forensic examination like detection of abuse drug in hair samples and in hair analysis [25]- [27]. In forensic medicine HSI finds its application for age estimation of human dentin [28] and characterization of condom lubricant components [29] by Raman micro-spectrometry imaging, age of bruises [30], blood stains at scene of crime and their age estimation [31]. Examination of inks, paints and fibers are performed by visible and near-infrared chemical imaging method [32] [33]. For questioned document examination purposes, systems are available with different light sources, excitation and barrier filters mainly used for differentiating inks [34] [35].

In modern offices, photocopies and printers (inkjet and laser) occupy an important part of routine work, also making them vulnerable tool in document forgeries. Researchers had reported examination of printed toners and printers in different aspects of document frauds and instrumental methods.

Although spectral data bases is created for discrimination of photocopy and printer toners [36], there is a need for application of HSI for inkjet and laser printers examination and their differentiation in dynamic system. Here in this study an attempt is made to differentiate laser and inkjet printed strokes on paper surface by using hyper spectral imaging technique for forensic document examination purpose. The method can be used for detection of print forgeries, alterations and page substitution of printed questioned documents as well as for the analysis of printers. Perhaps the most important distinction among inkjet and laser printers is their printing process and ingredients.

MATERIALS AND METHOD

Sample preparation

The samples for the study were prepared on a A4 size 75gsm sheet of paper by printing from seven models of inkjet printers and eleven laser printers (listed in Table-1). The printed text from each printer contained with name of manufacturing company and its model number to avoid any confusion or error in examination and comparison of results.

Hyper spectral image and spectral data acquisition

Hyper spectral imaging (HSI) was performed by video spectral comparator (VSC) 6000/HS by Foster and Freeman, UK. The instrument was calibrated at each spell of examination. VSC includes facility of HSI which uses band pass filters light sources to create an image cube of a document. This image cube can be photos of many images of the document.

Table-1 Eighteen printers considered in study with their brand name and model.

Brand	Model	printer
Epson	L220	Inkjet
	L110	Inkjet
	L210	Inkjet
	L800	Inkjet
	DCP-J105	Inkjet
	DCP-J300	Inkjet
	MFC- J430	Inkjet
Brother	DCP-7065DN	Laser Printer
	HL-L2321D	
Canon	3300	Laser Printer
Dell	113N	Laser Printer
Samsung	ML-3310ND	Laser Printer
	1020 Plus	Laser Printer
	P-1606DN	Laser Printer
Hewlett	2600N	Laser Printer
Packard	P2015	Laser Printer
	P1566	Laser Printer
	M1120N MFP	Laser Printer
PRO	M 706N	Laser Printer

The desired range of examination selected for the study was 400 to 1000 nm (visible and near IR). Instrument selects the region of interest (ROI) to reduce the background noise. Images of the sample were viewed via a continuously variable band pass filter, with a step width of 4 nm to generate a total of 151 images. Spectral data was acquired in reflectance mode. For white reference part of paper surface free from toner or any kind of ink is considered. The reflectance spectra were generated from the darkest part of printed strokes from both inkjet and laser printers samples, this reduces the effect and interference of color and quality of paper on spectral results. As instrument blocks all the external light there is no external noise interference in the spectral results obtained.

RESULTS AND DISCUSSION

The results demonstrate the potential of HSI associated with discrimination of inkjet & laser printers in document examination. Images of the sample (Fig-1, 2 and 3) resulted from a continuously variable band pass filter discriminates laser and inkjet printers.

The HSI of Inkjet printer models EpsonL220 and L210, Brother DCP-J105 and DCP-J300 and a laser printer Canon LBP 330 are illustrated in Fig-2, at visible wavelength all printed ink/toners are visible but as we proceed from 704 nm the inkjet printers starts filtering from laser Canon LBP 330 at increasing wavelength except Brother DCP-J300 (inkjet) do not show contrasting difference as visible in other inkjet. It is the only inkjet printer which resulted poor discrimination from other lasers at spectra range of 400-1000 nm.

HSI has proven to be a valuable technique for the imaging of inkjet and laser printers. The probability that two distinct samples selected at random from the parent population would be discriminated in at least one attribute if the series of attributes were determined .i.e. discriminating power is determined by method described by Smalldon and Moffat [37]

Discriminating power (DP) = No. of items discriminated / No. of all items

The discriminating power alone of imagery results of inkjet and laser printer is 0.94 whereas, spectral results gave a discriminating power of 01. A combined discriminating power of 97% is observed from spatial and spectra results the results are far better than the results shown by Tatiana Trejos 2014 [5] providing only 47.4% discrimination between possible comparison pairs and states that laser-based methods and Scanning Electron Microscopy-Energy Dispersive X-Ray Spectroscopy (SEM-EDS) methods are not appropriate for inkjet examinations.

In same study laser sampling methods were shown to provide discrimination greater than 94% for this same inkjet set with false exclusion and false inclusion rates lower than 4.1% and 5.7%, for LA-ICP-MS and LIBS respectively which is again lower than the DP obtained by hyper spectra imaging of the samples on paper.

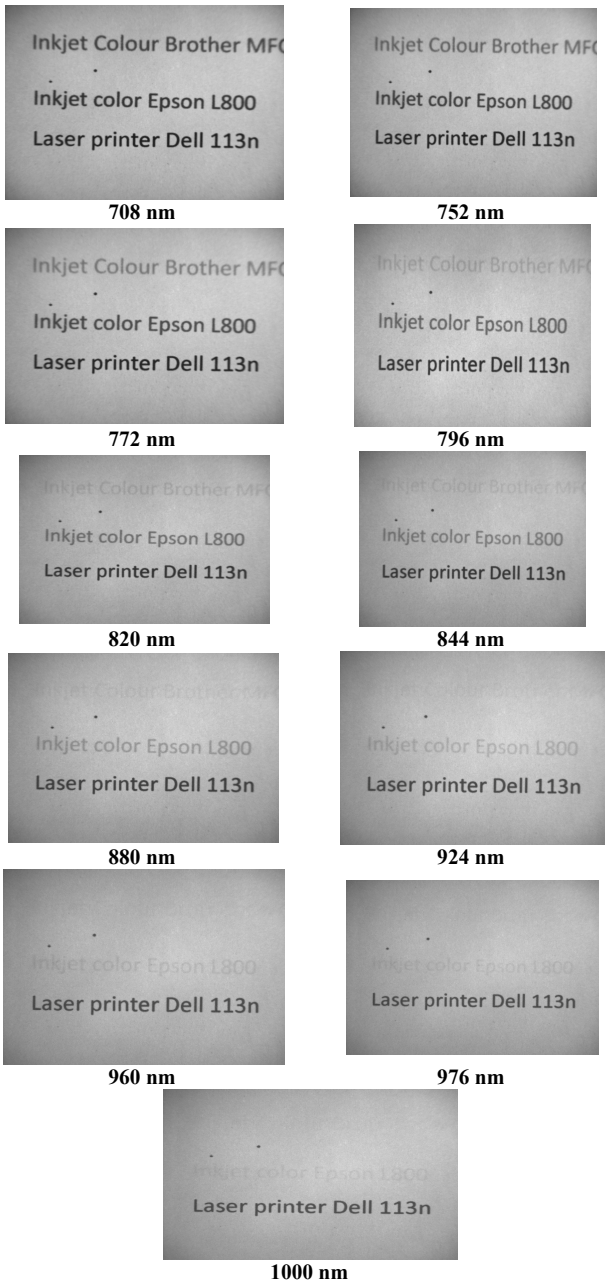

Fig-1, Images of hyper spectral analysis of paper containing four inkjet and one laser printer printed respective model on single sheet of paper. A spectral range 400 –1000 nm images with significant differences observed. Note the changes in image at visible wavelength and near IR wavelengths.

Direct analysis in real-time mass spectrometry (DART-MS) and attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) used in discrimination of inkjets, toners, offset, and intaglio gave data results in improved discrimination when both techniques are used in succession resulting in >96% discrimination for all toners, 95% for all inkjets, >92% for all offset, and >54% for all intaglio inks. However, DP of the present method is better than (97%) the reported method.

However, HSI within ranges of 400 - 1000nm restrict differentiation among models of inkjet and laser printers as very less variation in composition in laser toners is observed amongst manufacturers. HSI offers significant advantages, mainly because a large number of printed content can be analyzed at once making comparisons of different specimens easier and reducing the analysis time.

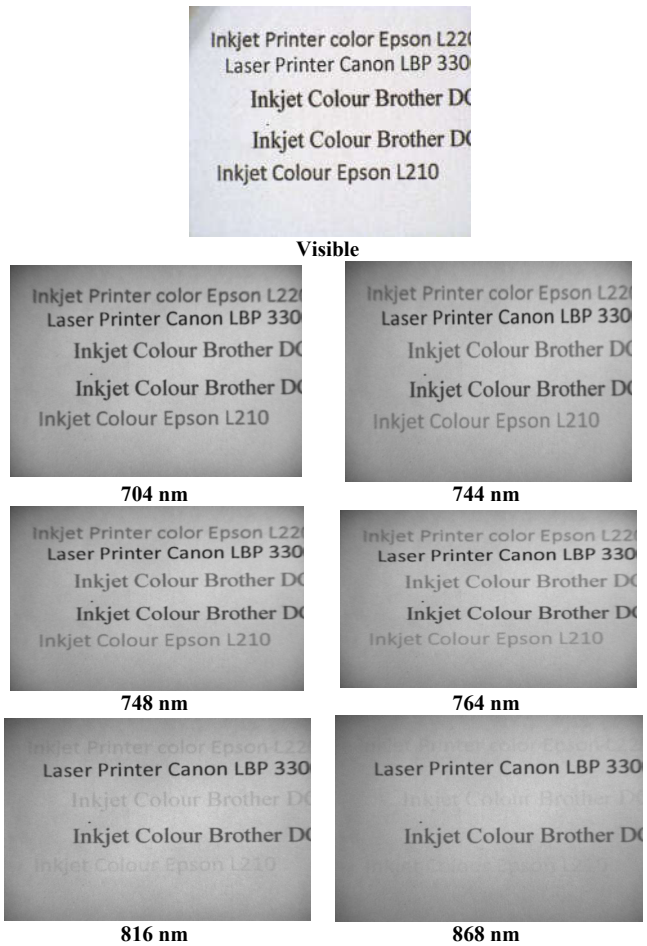

Fig-2 Imagery results of hyper spectral analysis of EpsonL220and L210, Brother DC and DC and a laser printer (Canon LBP 330) spectral range 400 –1000 nm images with significant differences observed.

The reflectance spectra representing % of maximum intensity verses wavelength of all the inkjet and laser printers reveal brand discrimination based on differences in spectral shape, slope and/or curve and wave length of maximum absorption (λ max) positions. From the spectral data alone (Fig-6 and 7), it was possible to discriminate inkjet printers from laser printed samples.

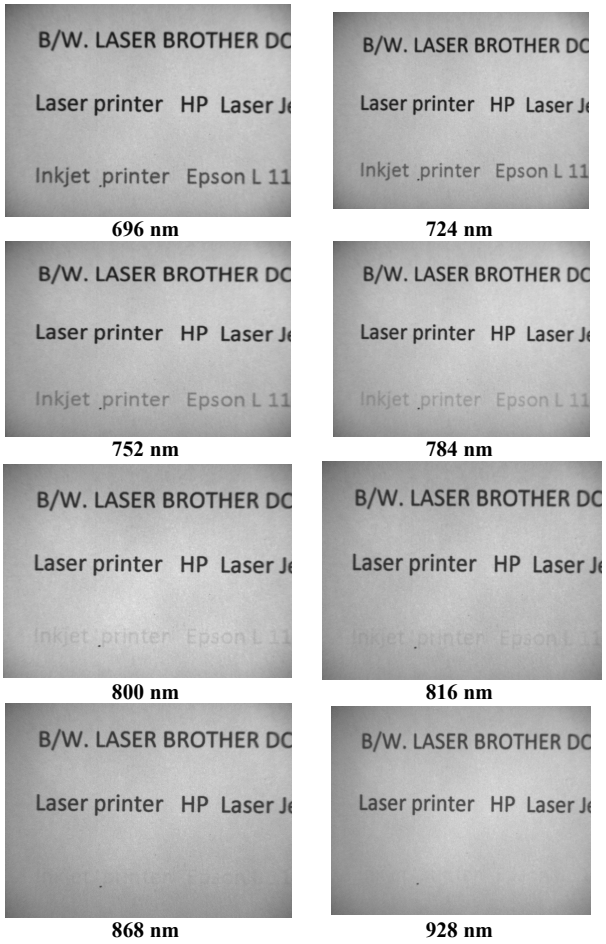

Fig-3

Fig.4, Results of three Laser printers Laser Jet P-1606DN, LaserJet 2600n and PRO M706N at a range of 600 - 1000 nm. No appreciable difference observed in this range in laser printers.

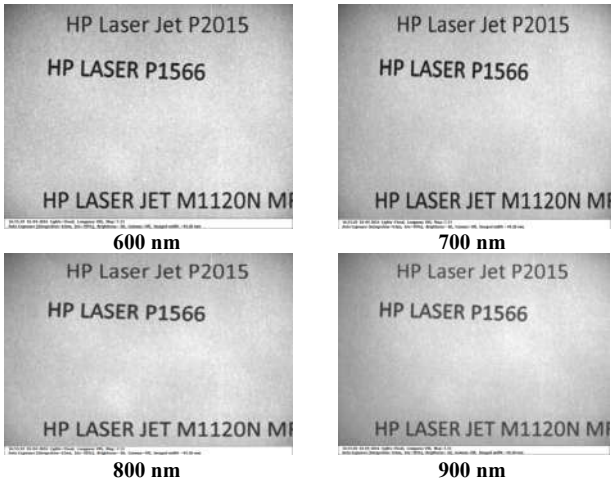

Fig.5

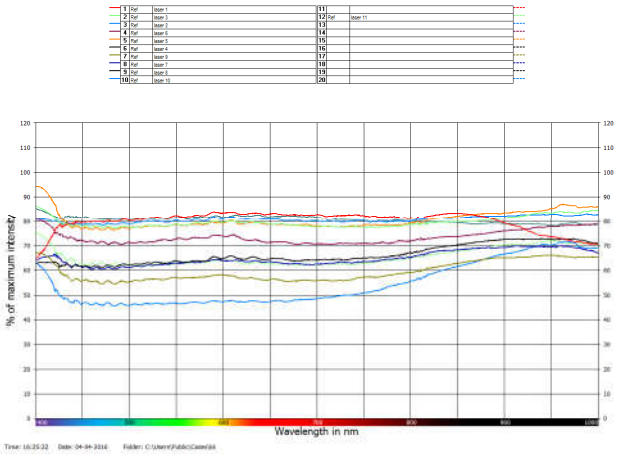

Fig- 6 % Reflectance spectra acquired from the printed strokes of eleven different Laser printer models.

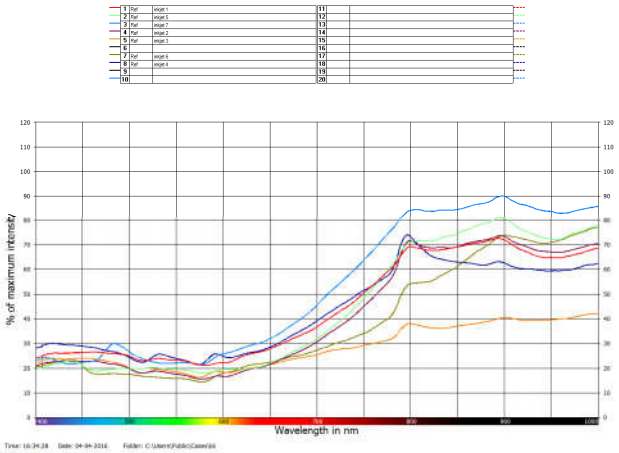

Fig- 7 % Reflectance spectra acquired from the printed strokes of seven different Inkjet printer models.

From % reflectance spectra of laser printers it is evident that the intensity remains somewhat uniform throughout the wavelength range due to more durable composition of laser toners (specific polymers used by manufacturers can be styrene acrylate copolymer, a polyester resin, a styrene butadiene co polymer) but definitely some change in intensity is observed beyond 900 nm. In inkjet printers reflectance spectra clearly rise in % intensity observed after 600 nm with a λ max at 798 nm discrimination in intensity within models. Inkjet is a dye and pigment based ink with water in composition along with organic solvents as alcohols and glycols, when these inks are exposed to band pass filter they show changes in their opacity at range of 600-1000 nm.

Comparison of DP of the present method with other reported methods.

A comparison of the DP of the present method with other reported methods like LA-ICP-MS, LBS and SEM-EDS shown that the present method using HIS gives better DP (97%) compared to other methods (Table 2) confirming the advantage of HIS approach.

CONCLUSION

Hyper spectral imaging offers significant advantages in forensic document examination. The simplicity, speed, easy to understand and represent visual and spectral results without the need for simple preparation makes it most desirable non-destructive technique for discrimination of inkjet and laser prints. The nondestructive nature protects the evidential value of document and scope for re-examination. It is quite simple and an effective technique for large volume of samples whose printing source is unknown. The results obtained (DP) from hyper-spectral analysis for discrimination of inkjet and laser printers, when compared with other methods earlier reported SEM-EDS, LA-ICP-MS and LIBS shows better discrimination from HSI. According to literature survey performed no other method reported discriminating power more than 97% in distinguishing inkjet and laser printers. By the proposed HSI method is nondestructive, simple and easy to perform, less time consuming, no pre analysis sample preparation which will be very useful in detection of alterations and forgeries at very minute level by printing.

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