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(54) SYSTEM AND METHOD FOR IMPROVED FORENSIC ANALYSIS

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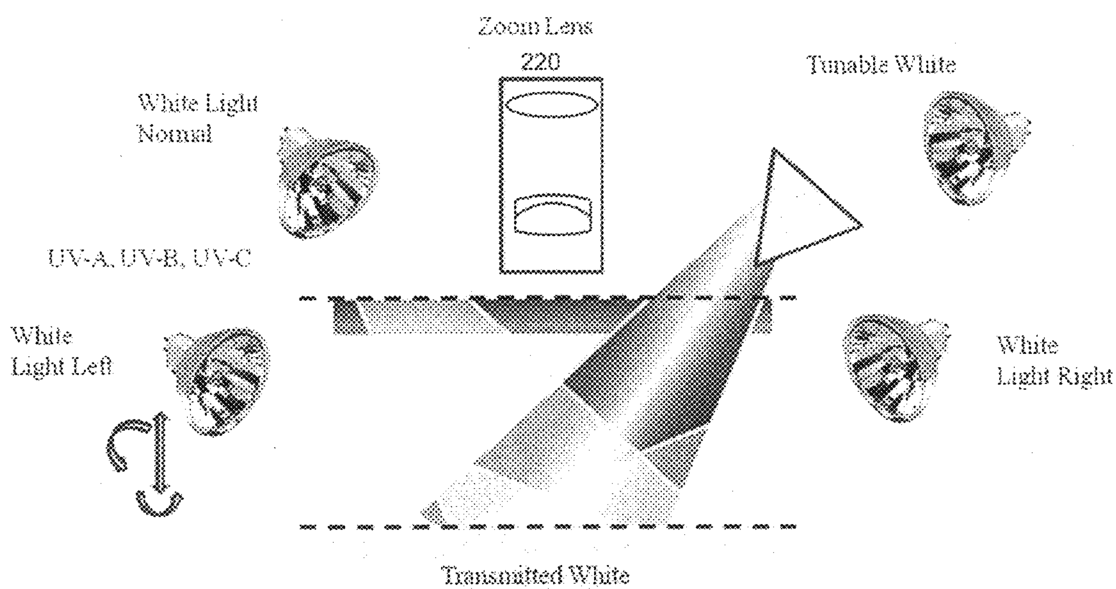
(57) **ABSTRACT**

The present disclosure provides for a system and method for analyzing questioned documents. A sample document is illuminated to thereby generate a first plurality of interacted photons. The first plurality of interacted photons are detected at a first detector to thereby generate a digital image. The digital image is analyzed to thereby identify at least one region of interest of the sample document. This region of interest is illuminated to thereby generate a second plurality of interacted photons. This second plurality of interacted photons are passed through a tunable filter and detected at a second detector to thereby generate a hyperspectral image representative of the region of interest. The hyperpsectral image may then be analyzed to evaluate changes to or differentiate different inks present in the sample document. Chemometric techniques such as k-means clustering, PCA, and/or PLSDA may also be applied.



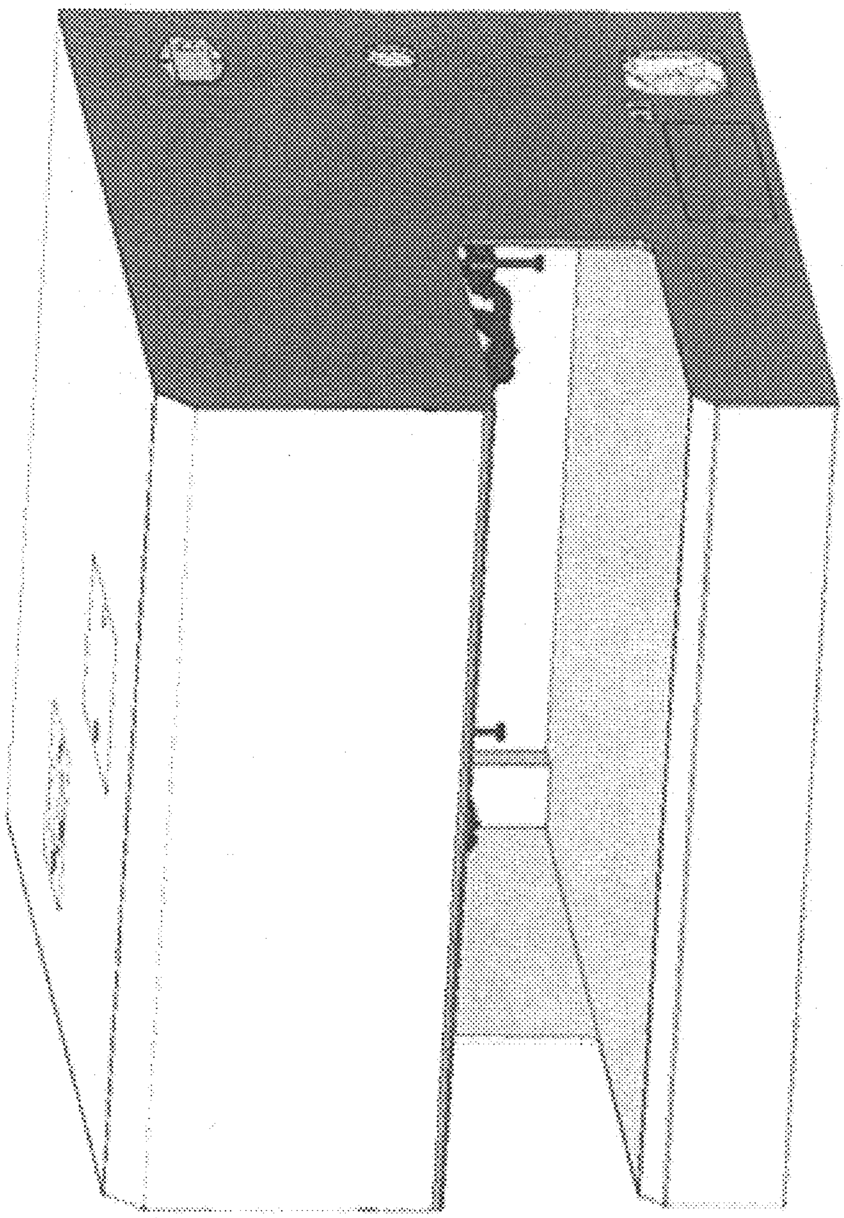


Figure 1

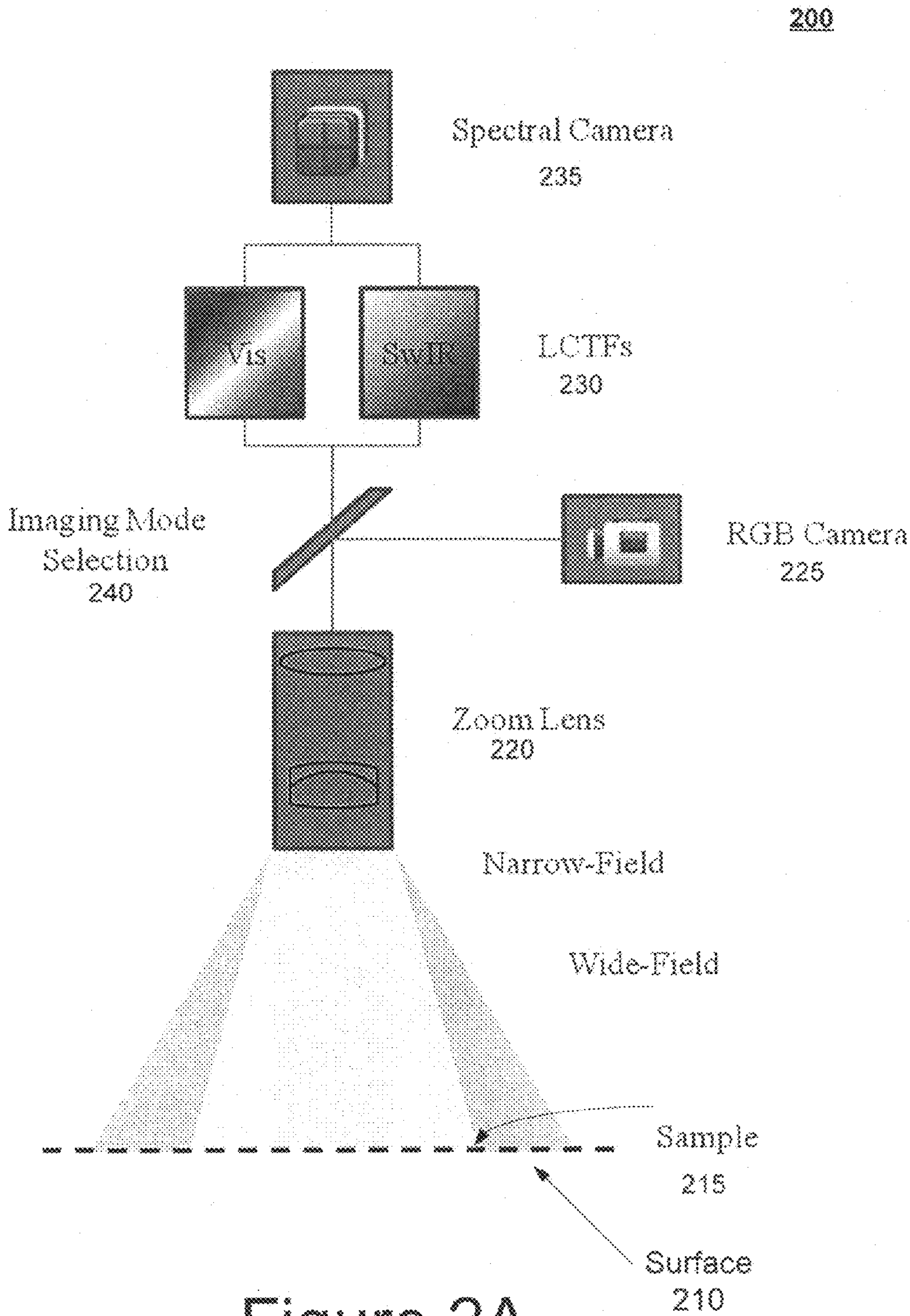

200
Spectral Camera
235
Vis
SWIR
LCTFs
230
Imaging Mode
Selection
240
RGB Camera
225
Zoom Lens
220
Narrow-Field
Wide-Field
Sample
215
Surface
210

Figure 2A

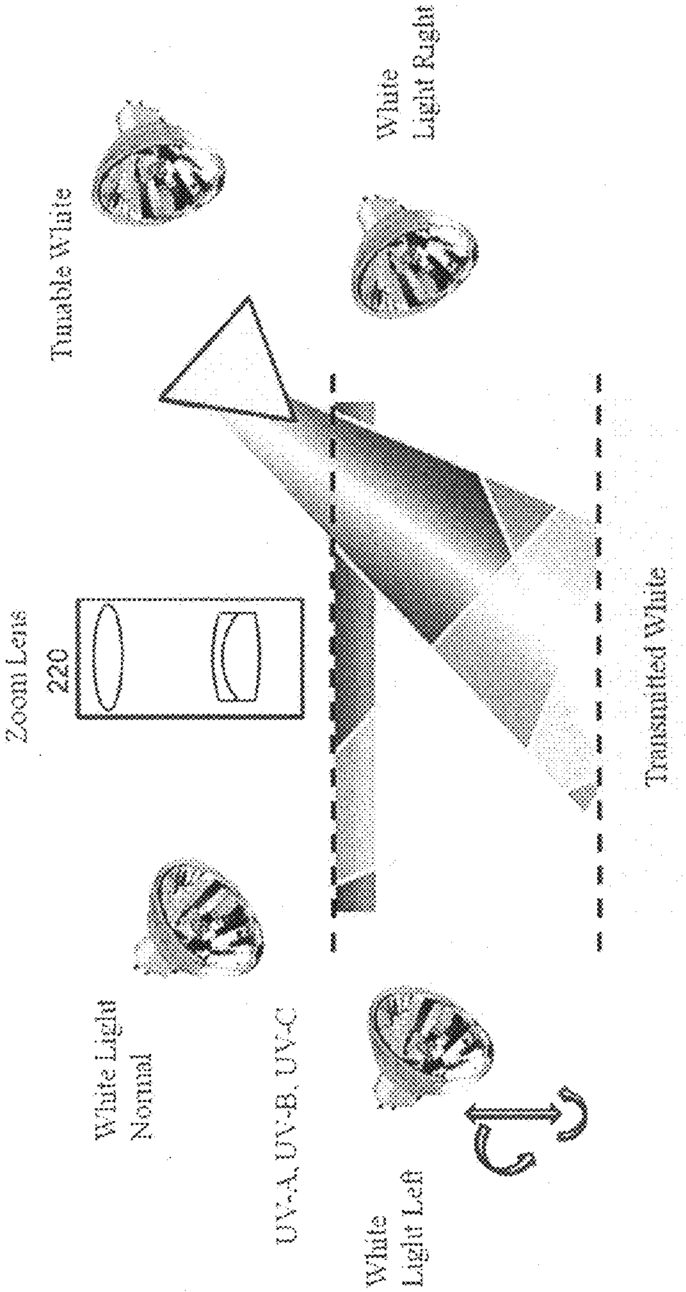

Tunable White
White
Light Right
Zoom Lens
220
Transmitted White
White Light
Normal
UV-A, UV-B, UV-C
White
Light Left

Figure 2B

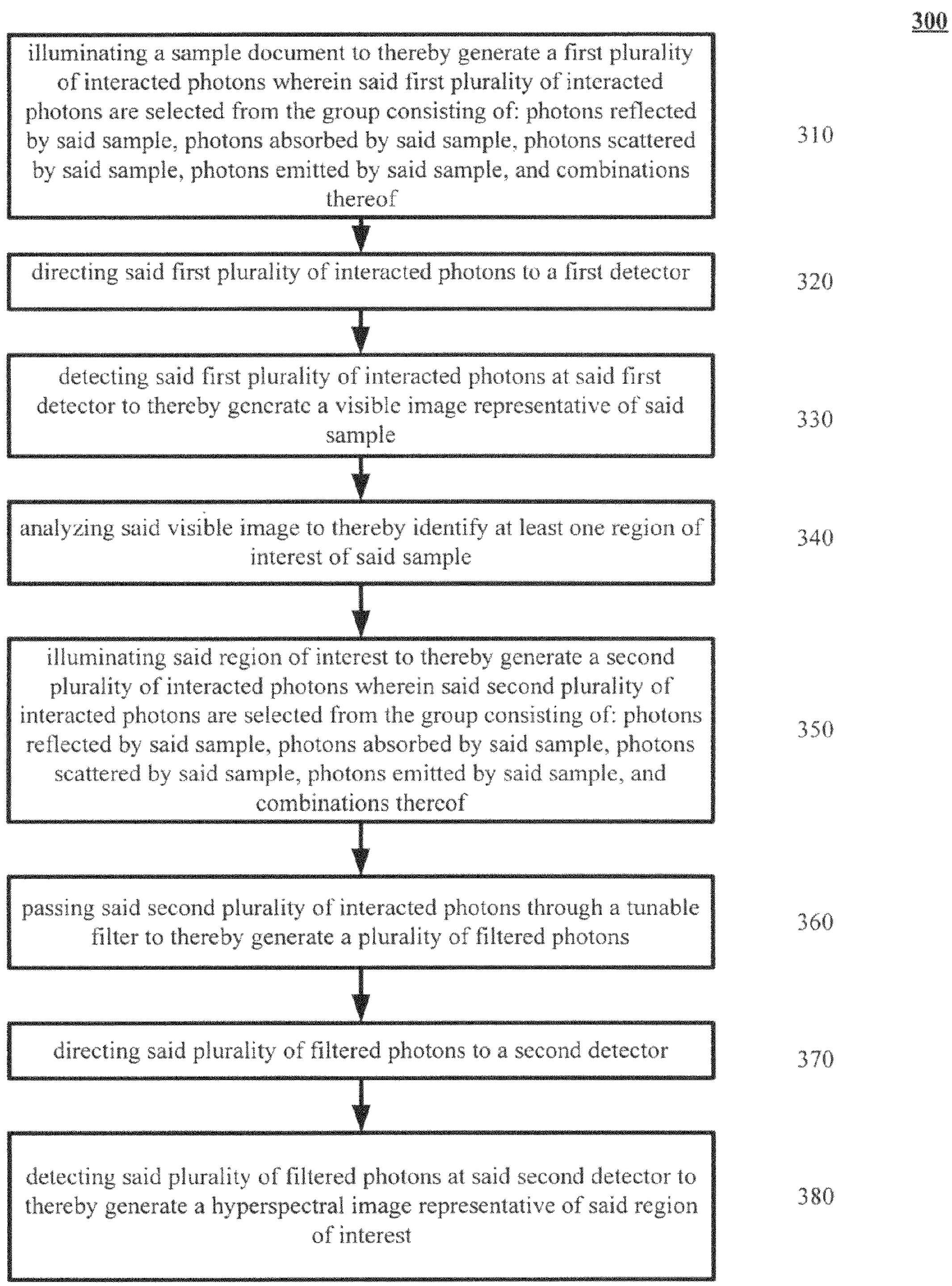

300
illuminating a sample document to thereby generate a first plurality of interacted photons wherein said first plurality of interacted photons are selected from the group consisting of: photons reflected by said sample, photons absorbed by said sample, photons scattered by said sample, photons emitted by said sample, and combinations thereof
310
directing said first plurality of interacted photons to a first detector
320
detecting said first plurality of interacted photons at said first detector to thereby generate a visible image representative of said sample
330
analyzing said visible image to thereby identify at least one region of interest of said sample
340
illuminating said region of interest to thereby generate a second plurality of interacted photons wherein said second plurality of interacted photons are selected from the group consisting of: photons reflected by said sample, photons absorbed by said sample, photons scattered by said sample, photons emitted by said sample, and combinations thereof
350
passing said second plurality of interacted photons through a tunable filter to thereby generate a plurality of filtered photons
360
directing said plurality of filtered photons to a second detector
370
detecting said plurality of filtered photons at said second detector to thereby generate a hyperspectral image representative of said region of interest
380

Figure 3

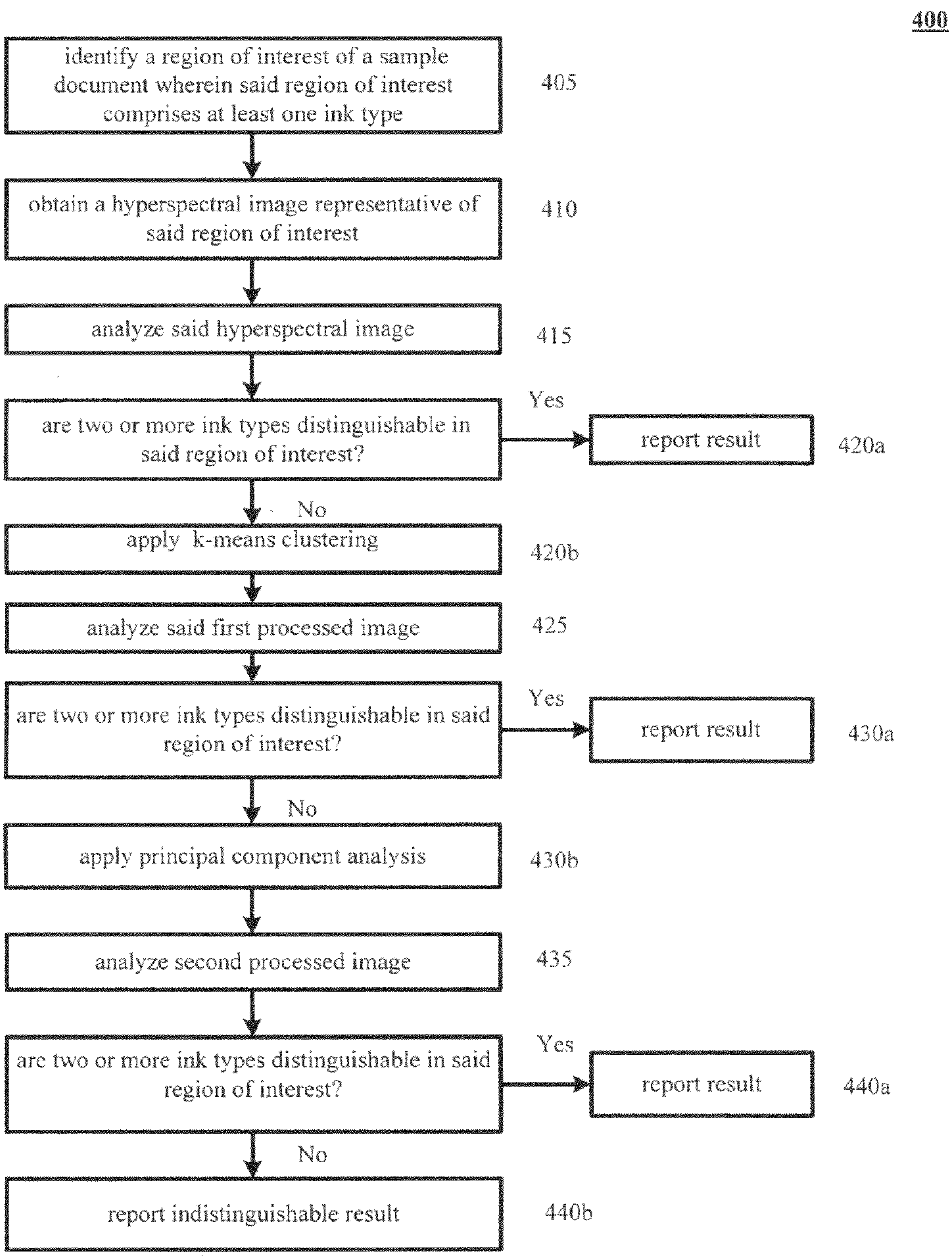

400
identify a region of interest of a sample document wherein said region of interest comprises at least one ink type
405
obtain a hyperspectral image representative of said region of interest
410
analyze said hyperspectral image
415
are two or more ink types distinguishable in said region of interest?
Yes
report result
420a
No
apply k-means clustering
420b
analyze said first processed image
425
are two or more ink types distinguishable in said region of interest?
Yes
report result
430a
No
apply principal component analysis
430b
analyze second processed image
435
are two or more ink types distinguishable in said region of interest?
Yes
report result
440a
No
report indistinguishable result
440b

Figure 4

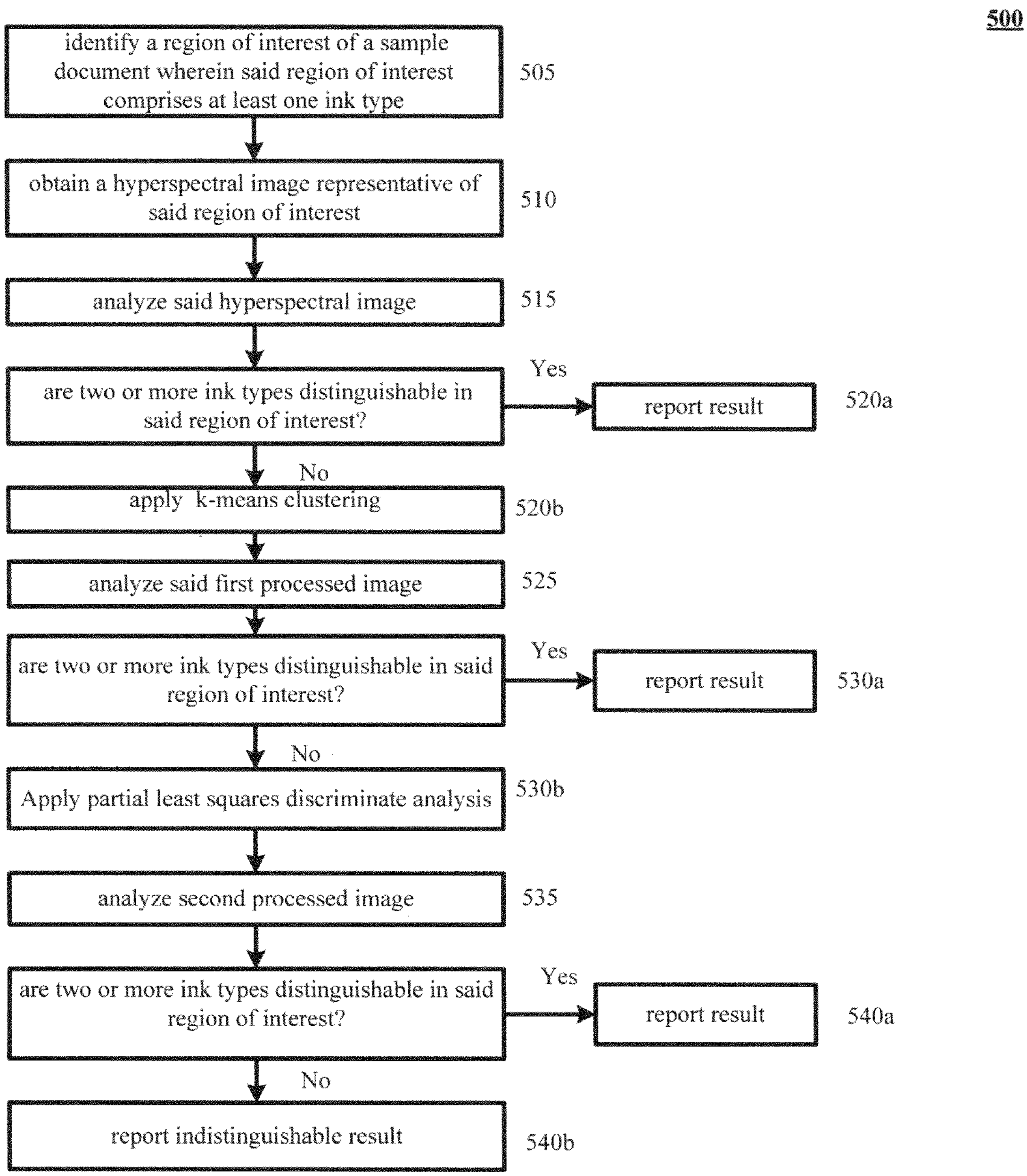
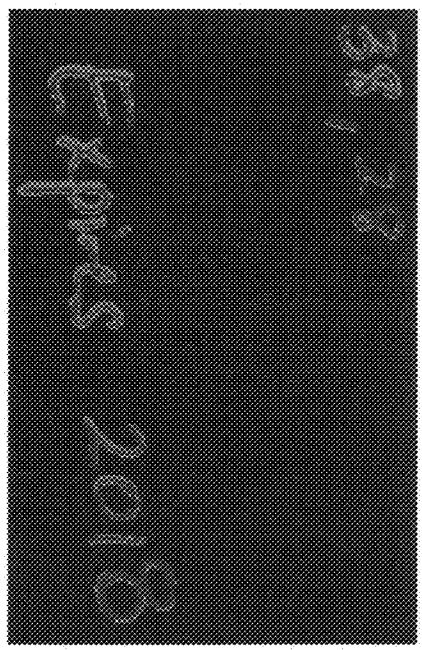

500
identify a region of interest of a sample document wherein said region of interest comprises at least one ink type
505
obtain a hyperspectral image representative of said region of interest
510
analyze said hyperspectral image
515
are two or more ink types distinguishable in said region of interest?
Yes
report result
520a
No
apply k-means clustering
520b
analyze said first processed image
525
are two or more ink types distinguishable in said region of interest?
Yes
report result
530a
No
Apply partial least squares discriminate analysis
530b
analyze second processed image
535
are two or more ink types distinguishable in said region of interest?
Yes
report result
540a
No
report indistinguishable result
540b

Figure 5

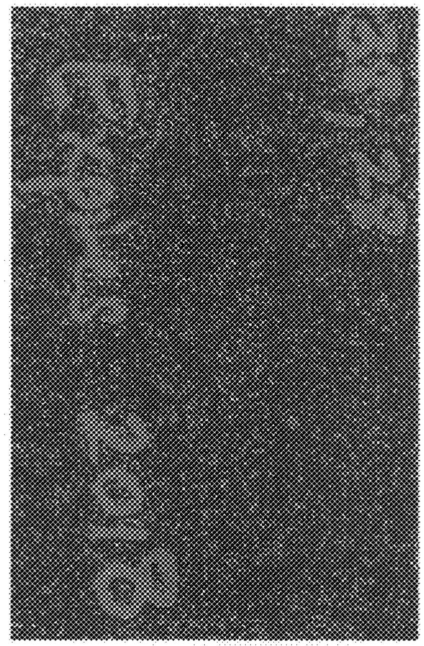
K-means Clustering and PLSDA Results

K-means clustering – 3 Classes



6A

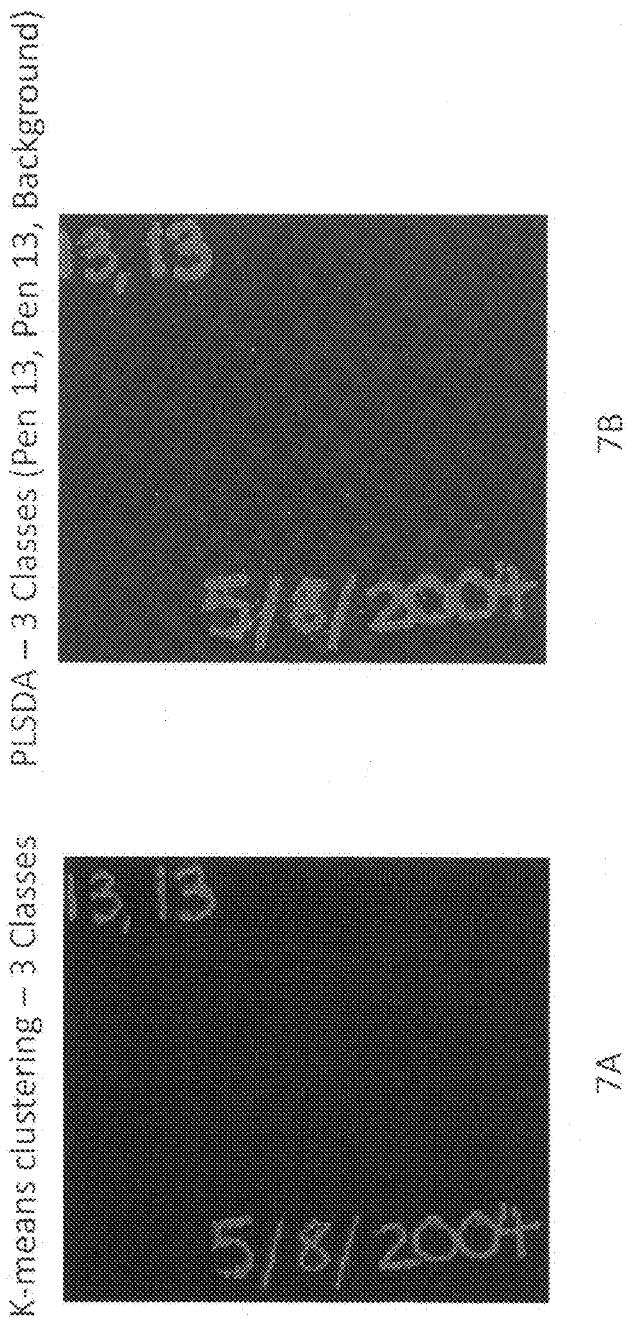
PLSDA – 3 Classes (Pen 38, Pen 28, Background)



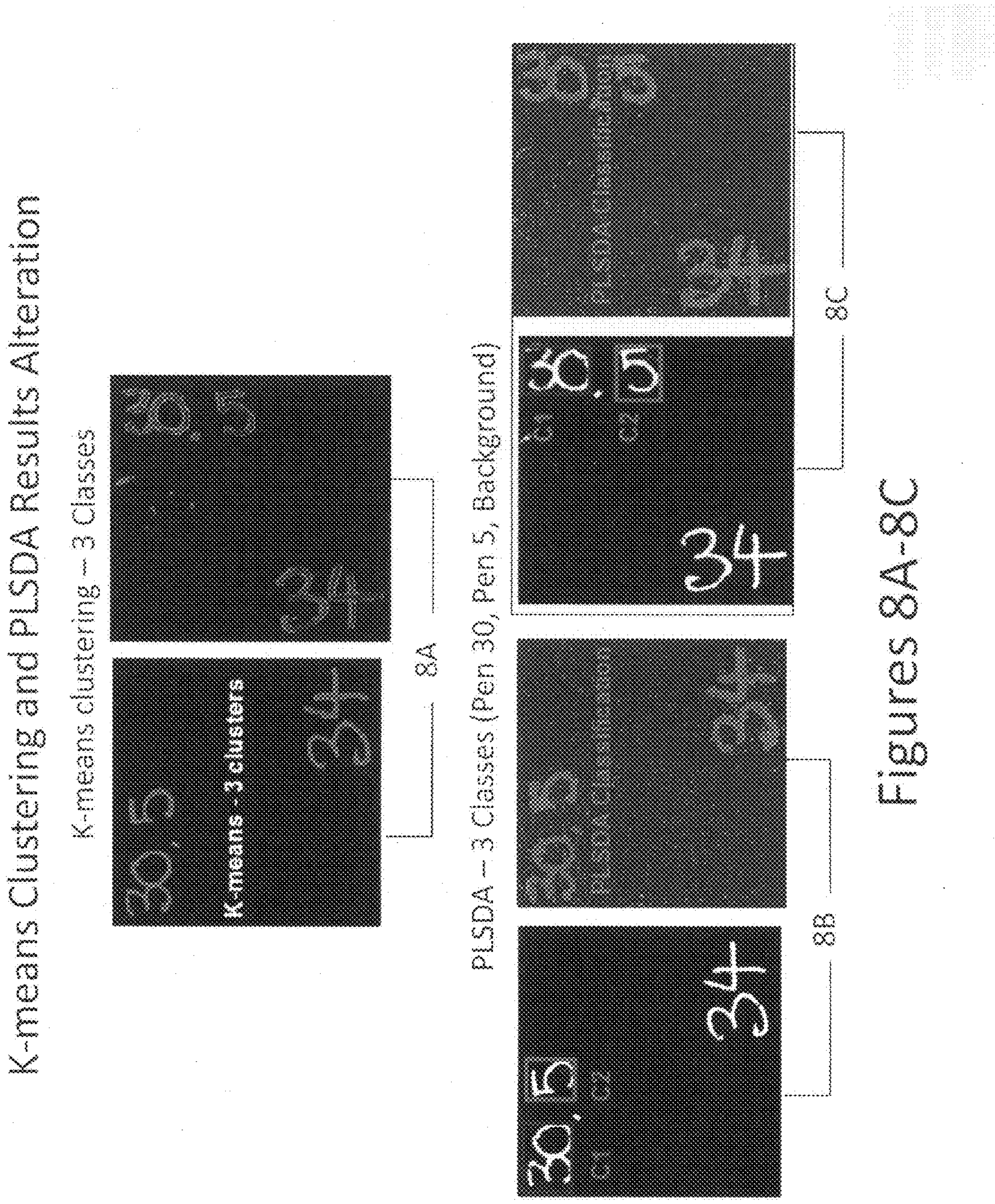
6B

Figures 6A and 6B

K-means Clustering and PLSDA Results
Negative Control



Figures 7A and 7B



Figures 8A-8C

SYSTEM AND METHOD FOR IMPROVED FORENSIC ANALYSIS

RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. §119(e) to U.S. Provisional Patent Application No. 61/231,077, filed on Aug. 4, 2009, entitled "Systems and Methods for Improved Forensic Analysis", which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] Forensic analysis involves the observation and identification of an object that may exist in part or in its entirety on some sort of supporting surface. This analysis typically compares the sample in question to other possible reference samples or reference data to make an association that relates it to a specific person, object, place or event. Forensic analysis is widely used in law enforcement or legal disputes as evidence in a range of situations from homicide to fraud. More specifically, the goal is usually to provide evidence of the existence of a direct link, for example, between a suspect and a crime scene, a victim and a suspect, a weapon and a suspect, etc. To do so with a high degree of specificity and discrimination from possible variations of the sample is essential. Examples of forensic samples include, but are not limited to, fingerprints, gunshot residues, condom lubricants, multi-layer paint chips, fibers, ink samples and thin layer chromatography plates.

[0003] The quality of a forensic analysis is critical in making the association of evidence as unambiguous as possible, thereby providing compelling identifications and linkages. In many cases, such as with fingerprints, this identification has widely accepted requirements where as in others, such as fiber characterization and comparison, the uniqueness of the results can be disputed. Even the most unique and definitive identification of biological evidence based on genetic information has been successfully questioned and removed as compelling evidence. Minimizing the subjective components or features of a forensic analysis to make compelling identifications and linkages therefore becomes a critical aspect of all forensic analysis. Doing so quickly and in a cost effective manner is equally important.

[0004] In most legal cases, the ability of a jury or judge to understand the forensic evidence, and the ability of the scientist to convey its value determines the utility of the forensic method. As a result, methods which allow the objects to be visually compared or which show simple representations of the item under scrutiny are the most widely accepted and understood by non-specialists. Despite the existence of many advanced scientific techniques and analysis methods that are very sophisticated, many such techniques may not be understood by non-specialists, and may thereby raise some doubts as to its validity. Visual forensic analysis and visual comparisons are amongst the most widely accepted forensic methods used to date.

[0005] Advances in science and technology have enabled many new approaches to sample analysis, bringing forensic science into an era which goes far beyond the classic perception of an investigator looking thru a magnifying glass for small traces of evidence. Numerous techniques exist that allow detailed chemical and elemental identification. This includes most all analytical chemistry methods, such as mass spectroscopy, x-ray analysis, scanning electron microscopy and chromatography, that are widely used today to characterize gaseous, liquid and solid materials. Many of these methods are extremely sensitive and require finite material for their use that is consumed as part of the analysis process. Advances in the sensitivity of analytical chemistry methods and instruments over the years have reduced this problem but these methods are still not considered non-destructive. This becomes increasingly important as smaller and smaller pieces of pieces of evidence are examined and required in forensic analysis. The examination of questioned documents consists of the analysis and comparison of questioned handwriting, hand printing, type writing, commercial printing, photocopies, papers, inks, and other documentary evidence with known material in order to establish the authenticity of the contested material as well as the detection of alterations. Forensic document examiners (FDEs) conduct examinations on a wide variety of evidence including medical records, wills, accounting records, checks, money and security documentation such as passports and visas.

[0006] Document examination may include: detecting forgeries, alterations, obliterations, additions or insertions, deletions, or other changes to documents; the identification or elimination of writing and/or printing with a known individual's writing; restoration of burned, faded, or water soaked documents; the identification, elimination, or classification of typewriting, typewriters, and elements, ribbons and correction materials; paper and ink analysis; dating of documents; searching documents for impressed wiring, typing, or other identifying impressions; photocopier identification, classification or comparison; rubber stamps or their impressions; anything to do with the production of documents or authenticity; among others.

[0007] Forensic document examiner conducts examinations on a wide variety of evidence. This can range from examining medical records to determine whether the entries were made at the time alleged, examining anonymous letters being sent by one employee to another, determined whether the signature on the will is the decedent's, deciphering an entry that has been covered with white-out, determining whether a particular photocopy was produced on a suspected machine and so on.

[0008] The examination of questioned documents consists of the analysis and comparison of questioned handwriting, hand printing, type writing, commercial printing, photocopies, papers, inks, and other documentary evidence with known material in order to establish the authenticity of the contested material as well as the detection of alterations.

[0009] Other techniques may include: thin layer chromatography TLC) and optical spectroscopy. TLC is a type of liquid chromatography that can separate chemical compounds of differing structure based on the rate at which they move through a support under defined conditions. TLC plates are used for separating color components of printing and writing inks and indirectly for ink dating. The unique way in which different inks separate into their individual components allows an examiner to identify the formulation and manufacturer. The manufacturer can then provide the earliest date at which this formulation was sold, providing some dating information. In addition to questioned document analysis, TLC analysis can be used for the analysis of trace evidence, explosive residue, insecticides, food toxins, biological materials and much more.

[0010] Spectroscopic imaging combines digital imaging and molecular spectroscopy techniques, which can include

Raman scattering, fluorescence, photoluminescence, ultraviolet, visible and infrared (including SWIR, NIR, MWIR, and LWIR) absorption spectroscopies. Raman spectra exhibit numerous features specific to molecular structure and can provide valuable "fingerprints" for comparing and differentiating materials. Surface enhanced resonance Raman scattering (SERRS) may also hold potential. When applied to the chemical analysis of materials, spectroscopic imaging is commonly referred to as chemical imaging. Instruments for performing spectroscopic (i.e. chemical) imaging typically comprise an illumination source, image gathering optics, focal plane array imaging detectors and imaging spectrometers.

[0011] In general, the sample size determines the choice of image gathering optic. For example, a microscope is typically employed for the analysis of sub micron to millimeter spatial dimension samples. For larger objects, in the range of millimeter to meter dimensions, macro lens optics are appropriate. For samples located within relatively inaccessible environments, flexible fiberscope or rigid borescopes can be employed. For very large scale objects, such as planetary objects, telescopes are appropriate image gathering optics.

[0012] For detection of images formed by the various optical systems, two-dimensional, imaging focal plane array (FPA) detectors are typically employed. The choice of FPA detector is governed by the spectroscopic technique employed to characterize the sample of interest. For example, silicon (Si) charge-coupled device (CCD) detectors or CMOS detectors are typically employed with visible wavelength fluorescence and Raman spectroscopic imaging systems, while indium gallium arsenide (InGaAs) FPA detectors are typically employed with near-infrared spectroscopic imaging systems.

[0013] Spectroscopic imaging of a sample can be implemented by one of two methods. First, a point-source illumination can be provided on the sample to measure the spectra at each point of the illuminated area. Second, spectra can be collected over the an entire area encompassing the sample simultaneously using an electronically tunable optical imaging filter such as an acousto-optic tunable filter (AOTF) or a liquid crystal tunable filter ("LCTF"). Here, the organic material in such optical filters are actively aligned by applied voltages to produce the desired bandpass and transmission function. The spectra obtained for each pixel of such an image thereby forms a complex data set referred to as a hyperspectral image which contains the intensity values at numerous wavelengths or the wavelength dependence of each pixel element in this image.

SUMMARY

[0014] Visible to near infrared (NIR) reflectance/absorbance, fluorescence imaging, optical microscopy and photography may be used as tools by questioned document examiners to identify, capture and characterize questioned documents. The present disclosure provides for extensions of these systems and methods to hyperspectral imaging ("HSI"). HSI may improve visualization and provide additional information about the sample's formulation. HSI combines standard digital imaging techniques with common spectroscopic methods to provide increased sensitivity and discrimination capabilities over traditional methods of questioned document analysis. HSI is nondestructive and requires little to no sample preparation, therefore decreasing the chances of possible contamination.

[0015] The advantage of HSI lies in the information embedded within the image. Because the images are a series of snapshots collected as a function of wavelength, each pixel within the image has a fully resolved spectrum associated with it. This method of data collection allows for better visualization and discrimination of a wider range of documents. Because the type of information contained in hyperspectral images is easier to interpret for non-scientists, the presentation of data and information to jurors in the courtroom is easy and straightforward.

[0016] A hyperspectral image is obtained by collecting digital images as a function of wavelength through the use of an electro-optic tunable imaging filter. Images can be collect through the visible to NIR range (400-1100 nm) in reflectance mode (broadband white light illumination) or through the visible range (400-720 nm) in fluorescence made (300-400 nm UV excitation). Because the images are collected as a function of wavelength, each pixel within the image has a fully resolved reflectance or fluorescence spectrum associated with it. Following data acquisition, image processing software may be used to generate univariate (i.e. single wavelength) images characteristic of absorbance, reflectance, or fluorescence exhibited by inks of interest. This imaging software may comprise ChemImage Xpert™, available from ChemImage Corporation, Pittsburgh, Pa. Alternatively, through the use of multivariate (i.e., multiple wavelengths) statistical tools, the software takes advantage of the viability present at a range of wavelengths to enhance image contrast and reveal minor differences between inks. Conventional imaging-based document analysis systems that rely on single wavelength images are not capable of this superior level of image enhancement.

[0017] HSI differs from the conventional method of document examination in that it may utilize a multi-conjugate filter (MCF), based on liquid crystal technology, in place of a general barrier filter/camera configuration. The MCF is a computer controlled, electro-optic device that can be tuned to transmit any discreet wavelength across the visible or NIR region of the spectrum (i.e., 400-1100 nm). Potential benefits of using an MCF are more fully described in U.S. patent application Ser. No. 12/765,188, filed on May 24, 2010, entitled "System and Method for Improved Forensic Analysis", which is hereby incorporated by reference in its entirety. Because different brands and types of inks have varying formulations, the absorbance, reflectance or luminescence properties of the inks will differ.

[0018] The present disclosure relates generally to forensic analysis of questioned documents. More specifically, the present disclosure provides for a system and method for analyzing questioned documents using hyperspectral imaging. The system and method provided for herein hold potential for distinguishing between ink types present in a sample document. The ability to distinguish between ink types may hold potential for determining whether or not a sample document has been altered in some way.

[0019] The system and method of the present disclosure overcome shortcomings present in the prior art. The system and method provided for herein allow for quick and accurate analysis of sample document based on visual inspection by a user. Being able to visually distinguish between ink types present in a sample document allows for results that can be easily interpreted.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The accompanying drawings, which are included to provide further understanding of the disclosure and are incorporated in and constitute a part of this specification, illustrate embodiments of the disclosure and, together with the description, serve to explain the principles of the disclosure.

[0021] FIG. **1** is a schematic representation of an exemplary packaging option of a system of the present disclosure.

[0022] FIG. **2**A is a schematic representation of a system of the present disclosure.

[0023] FIG. **2**B is a schematic representation of a various illumination configurations of a system of the present disclosure.

[0024] FIG. **3** is representative of a method of the present disclosure.

[0025] FIG. **4** is representative of a method of the present disclosure.

[0026] FIG. **5** is representative of a method of the present disclosure.

[0027] FIG. **6** is illustrative of exemplary results of a method of the present disclosure.

[0028] FIG. **7** is illustrative of exemplary results of a method of the present disclosure.

[0029] FIG. **8** is illustrative of exemplary results of a method of the present disclosure.

DETAILED DESCRIPTION

[0030] Reference will now be made in detail to the embodiments of the present disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[0031] The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee

[0032] The present disclosure provides for a system for analyzing questioned documents. FIG. **1** is illustrative of an exemplary packaging option of a system of the present disclosure. FIG. **2**A is a schematic representation of a'system of the present disclosure. The system **200** may be referred to commercially as the "HSI Examiner" available from ChemImage Corporation, Pittsburgh, Pa. The system may be used for ink discrimination studies, to identify alterations or forgeries, visualize hidden security features, examine travel documents, and imaging TLC plates, among other applications.

[0033] The system **200** comprises an illumination source (illustrated in FIG. **2**B). In one embodiment, the illumination source may comprise a broadband white light illumination source. In one embodiment, illustrated by FIG. **2**B, the broadband white light illumination may be configured to illuminate the sample document at a plurality of different angles. In one embodiment, an illumination source may be configured so as to illuminate a sample document or region of interest with oblique illumination. In one embodiment, the system **200** may also comprise at least one ultraviolet light source. This ultraviolet light source may comprise at least one of: UV-A, UV-B, UV-C, and combinations thereof.

[0034] Referring again to FIG. **2**A, the system **200** comprises a surface **210** for placing the sample document **215** for analysis. In one embodiment, this surface may comprise a platform. In one embodiment, the system may further comprise a light-tight enclosure. The system **200** may also comprise collection optics for collecting a plurality of interacted photons generated as a result of illuminating the sample document **215**. In FIG. **2**A, the collection optics is depicted as comprising a zoom lens **220**. An embodiment comprising a zoom lens may allow for varying focal length. In one embodiment, the system **200** may be configured with collection optics that allow for imaging approximately half a 8.5°×11' sheet of paper with the ability to zoom up to 0.5×0.4 inches, with 600 dpi (121 p/mm) resolution. These configurations are provided as an example of one embodiment of the present disclosure and do not limit other embodiments of the system and method disclosed herein.

[0035] The system **200** may also comprise a first detector, illustrated in FIG. **2**A as a RGB camera **225**. In one embodiment, this first detector may comprise a RGB color camera. RGB color cameras hold potential for high resolution, court friendly digital imaging. A means for directing the plurality of interacted photons through said system **200** is illustrated in FIG. **2**A as element **240**. Element **240** may comprise a polarization beamsplitter and/or a mirror. Element **240** may also be referred to as providing for "Imaging Mode Selection" because it can direct the plurality of interacted photons to either the first detector **225** for digital imaging or the second detector **235** for hyperspectral imaging. In one embodiment, the second detector **235** may comprise a spectral detector. In one embodiment, the second detector **235** may be selected from the group consisting of: a charge coupled device, a complementary metal-oxide-semiconductor, a intensified charge coupled device, and combinations thereof.

[0036] In one embodiment, discrete wavelengths of light may be projected on to a charge-coupled device (CCD) camera. This may provide up to 65 nm 535 channels of grayscale color, providing significant sensitivity to any differences in ink or other features of interest in a questioned document. In one embodiment, the second detector may comprise a front-illuminated CCD with enhanced NIR QE and/or a cooled CCD for reduced noise in long exposure fluorescence experiments.

[0037] Hyperspectral imaging provides very high spectral resolution, on the order of 5 nm, which allows the differentiation of image components with subtle differences (i.e., black inks). Combining high resolution spectral and spatial information allows identification of these compounds on complex samples. In one embodiment of the present disclosure, a spectral imaging range of 400 nm to 1100 nm may be used. In another embodiment, a spectral tuning resolution of 1 nm may be used.

[0038] The system **200** may also comprise one or more tunable filters **230**. In one embodiment, this filter may comprise a filter selected from the group consisting of: a multi-conjugate tunable filter, a liquid crystal tunable filter, acousto-optical tunable filters, Lyot liquid crystal tunable filter, Evans Split-Element liquid crystal tunable filter, Solc liquid crystal tunable filter, Ferroelectric liquid crystal tunable filter, Fabry Perot liquid crystal tunable filter, and combinations thereof.

[0039] In one embodiment, the hyperspectral imaging system of the present disclosure may be based on liquid crystal technology. This technology holds potential for providing unparallel image fidelity, as well as increased spectral resolution in comparison to the forensic imaging technology of the prior art. This improved spectral resolution provides the basis for increased discrimination and contrast enhancement capabilities. This imaging filter may be controlled through software to transmit discrete wavelengths of light, eliminating the need for numerous barrier or interference filters.

[0040] In one embodiment, the system of the present disclosure may comprise multi-conjugate filter technology available from ChemImage Corporation, Pittsburgh Pa. This technology is more fully described in U.S. Pat. No. 6,992,809, filed on Feb. 2, 2005, entitled "Multi-Conjugate Liquid Crystal Tunable Filter" and U.S. Pat. No. 7,362,489, filed on Apr. 22, 2005, also entitled "Multi-Conjugate Liquid Crystal Tunable Filter." These patents are hereby incorporated by reference in their entireties.

[0041] The system provided for herein may utilize reflected, transmitted, emitted, or scattered light from each point in the sample image to create chemical-based contrast within the image. Images are collected as a function of wavelength; therefore each pixel within the image has a fully resolved spectrum associated with it. By evaluating both spatial and spectral information, areas of interest and background substrates can be resolved.

[0042] Hyperspectral imaging technology provides high spatial and spectral resolution images for increase sensitivity and contrast enhancement for ink discrimination. The nondestructive analysis provides for the preservation of evidence, allowing for additional analysis. The system requires no sample preparation, so documents can be placed directly under the imaging optics for examination. A custom software package may be implemented to provide for an easy user interface that does not require examiners or be ink chemists or specialists.

[0043] The present disclosure also provides for a method for analyzing a questioned document. One embodiment of a method of the present disclosure is illustrated in FIG. **3**. The method **300** comprises illuminating a sample document in step **310** to thereby generate a first plurality of interacted photons. In one embodiment, this first plurality of interacted photons may be photons selected from the group consisting of: photons reflected by said sample document; photons absorbed by said sample document; photons scattered by said sample document; photons emitted by said sample document; and combinations thereof. In step **320** this first plurality of interacted photons are directed to a first detector. In step **330** this first plurality of interacted photons are detected at the detector to thereby generate a digital image representative of the sample document. In one embodiment, the digital image may comprise a RGB image. This digital image is analyzed in step **340** to thereby identify at least one region of interest of said sample. In one embodiment, this region of interest may comprise an area of said sample document suspected of comprising an alteration to said sample document. This alteration may comprise at least one of: an addition, and obliteration, a deletion, or other change to the sample document. In another embodiment, this region of interest may be an area of said sample document suspected of comprising more than one type of ink. Comprising more than one type of ink may be further evidence that an alteration has been made to a sample document.

[0044] A region of interest is illuminated in step **350** to thereby generate a second plurality of interacted photons. In one embodiment, this illumination may be achieved using broadband white light. In one embodiment, this second plurality of interacted photons may be photons selected from the group consisting of: photons reflected by a region of interest; photons absorbed by a region of interest; photons scattered by a region of interest; photons emitted by a region of interest; and combinations thereof. In step **360** the second plurality of interacted photons are passed through a tunable filter to thereby generate a plurality of filtered photons. In one embodiment, these filtered photons may comprise wavelength-selective filtered photons. The plurality of filtered photons are directed to a second detector in step **370**. In one embodiment, this second detector may comprise a spectral detector. These filtered photons are detected at said second detector to thereby generate a hyperspectral image representative of the region of interest in step **380**. In one embodiment, the hyperspectral image comprises an image and a fully resolved spectrum unique to the material for each pixel location in said image. In one embodiment, this hyperspectral image may comprise a visible hyperspectral image.

[0045] In one embodiment, the hyperspectral image may be analyzed to thereby determine if the region of interest comprises an alteration. In another embodiment, the hyperspectral image may also be analyzed to determine whether or not the sample comprises more than one ink type. In another embodiment, the method may further comprise applying one or more chemometric techniques to said hyperspectral image. This technique may be any known in the art, including but not limited to: principle component analysis, partial least squares discriminate analysis, cosine correlation analysis, Euclidian distance analysis, k-means clustering, multivariate curve resolution, band t. entropy method, mahalanobis distance, adaptive subspace detector, spectral mixture resolution, and combinations thereof. In another embodiment, pattern recognition algorithms may be used.

[0046] The present disclosure contemplates that more than one region of interest may be identified in said sample document. Therefore, in one embodiment, the present disclosure provides for obtaining a hyperspectral image for each of the regions of interest that may be present in the sample document. These hyperspectral images can then be analyzed to determine if the region of interest comprises an alteration. The hyperspectral image may also be analyzed to determine of the region of interest comprises more than one ink type.

[0047] In one embodiment of the present disclosure, the method provided for herein may be automated or semi-automated. In one embodiment, this automation may be achieved using software. In another embodiment, analysis is performed on only those pixels in a hyperspectral image comprising ink. In such an embodiment, the background pixels (those pixels not comprising ink) are separated from the ink pixels. This may be performed automatically or semi-automatically. By excluding these background pixels, confusion can be reduced, hold potential for a more discriminative result. Therefore, in one embodiment of the present disclosure one or more chemometric techniques may be applied to only the ink pixels.

[0048] In one embodiment of the present disclosure, preprocessing steps may be performed in conjunction with the various embodiments of the method disclosed herein. These preprocessing steps may comprise prescreening a sample document and zooming in on a region of interest. The lighting may be adjusted, acquisition conditions defined, and sample ink data acquired. If spectralon data is pre-acquired, then spectralon division may be done in memory when a sample data frame is acquired. An algorithm may be utilized to automatically detect sample pixels (pixels comprising ink) and background pixels. An algorithm may also be used to select a subset of background pixels and compute the average spectrum from selected pixel spectra. This average spectrum may be used for background division. If necessary, data may also be converted to absorbance data.

[0049] In one embodiment of the present disclosure, the number of analysis steps performed may rely on the data under analysis. In one embodiment, whether or not a first, second, etc. technique is applied may be determined by a user based on visual inspection of the data. For example, if a sample comprises two inks with very different characteristics, they be distinguishable based on visual inspection of a digital image. In harder cases, it may be necessary to perform additional analysis of hyperpsectral images by applying processing techniques and/or chemometric techniques. For example, k-means clustering may be applied to the data in an attempt to enhance distinctions between inks. In another embodiment, the results of the chemometric techniques applied may be verified by evaluation of at least one spectra associated with at least one ink present in the region of interest. Therefore, the present disclosure contemplates the use of visual inspection and/or spectral verification (which may be automatically performed) for determination of how may chemometric techniques need to be applied.

[0050] In harder cases, a second technique may be applied if the first technique was not successful in clearly articulating between ink types. In one embodiment, principal component analysis ("PCA") may be applied to data where digital imaging was not able to display distinctions between inks. In other harder cases, partial least squares discriminate analysis ("PLSDA") may be applied to the data.

[0051] In one embodiment, implementation of PLSDA may comprise building a training set. In such an embodiment, a user may select one or more regions of interest. In one embodiment, these regions of interest are such that only sample pixels (pixels comprising ink) are included. In one embodiment, the number of regions of interest may be equal to the number of inks in a parent document. This parent document may comprise a document wherein the number and location of ink types are known. In one embodiment, for each region of interest, if the number of ink pixel spectral is ≧200, 100 spectra may be randomly selected to form a class. In such an embodiment, if the number of ink pixel is <200 then approximately 50% of the spectra may be randomly selected. In one embodiment, 200 background pixels (pixels not comprising ink) may be automatically selected to form a background class.

[0052] A PLSDA model may be built using class spectra and class number. In one embodiment, PLSDA may be applied as a two class or a three class problem. The model may then be applied to a hyperspectral image representative of a region of interest of the sample document. The classification image (also referred to herein as the "second processed image") may be displayed. A user may evaluate the classification image to thereby determine of two or more inks can be distinguished in the region of interest. This evaluation may be based on visual inspection.

[0053] In one embodiment, these different analysis methods may be used to classify inks into different groups based on the type of ink. In one embodiment, each ink in a class may be assigned a color. In one embodiment, this may generate what may be referred to as a "colorized classified image."

[0054] FIG. **4** is representative of a method of the present disclosure. The method **400** comprises identifying a region of interest of a sample document in step **405** wherein said region of interest comprises at least one ink type. A hyperspectral image of the region of interest is obtained in step **410**. In step **415** the hyperspectral image is analyzed. In one embodiment, this analysis may comprise visual inspection by a user. Visual inspection by a user may be based on differences in color or shading between two or more inks. If two or more ink types are distinguishable from one another in step **415**, then a result is reported in step **420***a*. In one embodiment, the report in **420***a* may comprise a determination that the region of interest comprises at least one of: an alteration, an addition, a deletion, obliteration, or another change to the sample document. The presence of two or more different inks in a sample document may be an indication that a change has been made to the original document.

[0055] If two or more inks are not distinguishable in step **415**, then a first chemometric technique may be applied to said hyperspectral image to generate a first processed image representative of said region of interest in step **420***b*. In one embodiment, illustrated by FIG. **4**, this first chemometric technique may comprise k-means clustering. The first processed image is analyzed in step **425**. In one embodiment, analysis of a first processed image may comprise visual inspection by a user. If two or more inks are distinguishable in step **425** then a result may be reported in step **430***a*. If two or more inks are not distinguishable in step **425**, then a second chemometric technique may be applied to generate a second processed image in step **430**. In one embodiment, this second chemometric technique may comprise partial least squares discriminate analysis ("PLSDA"). The second processed image may be analyzed in step **435** to thereby determine if two or more inks can be distinguished in the region of interest. If two or more inks are distinguishable, then a result may be reported in step **440***a*. If two or more inks cannot be distinguished in step **435**, then an indistinguishable result may be reported in step **440***b*. In one embodiment an indistinguishable result may be indicative of the region of interest comprising only one ink type. This may infer that either no change was made to the document, or any change made to the document was done with the exact ink type of the original document.

[0056] FIG. **5** is representative of a method of the present disclosure. The method **500** comprises identifying a region of interest of a sample document in step **505** wherein said region of interest comprises at least one ink type. A hyperspectral image of said region of interest is obtained in step **510**. The hyperspectral image is analyzed in step **515** to thereby determine if two or more ink types are distinguishable in said region of interest. If two or more ink types are distinguishable in step **515**, then a result can be reported in step **520***a*. If two or more ink types cannot be distinguished in step **515**, then a first chemometric technique may be applied to the hyperspectral image to generate a first processed image representative of the region of interest in step **520***b*. In one embodiment, illustrated in FIG. **5**, the first chemometric technique may comprise k-means clustering. The first processed image may be analyzed in step **525** to determine if two or more inks are distinguishable in the region of interest. If two or more inks are distinguishable, then a result may be reported in step **530***a*. If two or more inks cannot be distinguished in step **525**, then a second chemometric technique may be applied to thereby generate a second processed image in step **530***b*. In one embodiment, illustrated by FIG. **5**, the second chemometric technique may comprise principle component analysis. The second processed image may be analyzed in step **535** to thereby determine if two or more ink types are present in said region of interest. If two or more ink types can be distinguished in step **535**, then a result may be reported in step **540***a*. If two or more ink types cannot be distinguished in step **535**, then an indistinguishable result may be reported in step **540***b*.

[0057] The present disclosure may be embodied in other specific forms without departing from the spirit or essential attributes of the disclosure. Accordingly, reference should be made to the appended claims, rather than the foregoing specification, as indicating the scope of the disclosure. Although the foregoing description is directed to the embodiments of the disclosure, it is noted that other variations and modifications will be apparent to those skilled in the art, and may be made without departing from the spirit of the disclosure.

Example

[0058] Pen samples were prepared at ChemImage Corporation, Pittsburgh, Pa. Five brands of pens were used: (1) Bic®; (2) PaperMate®; (3) Pilot®; (4) Universal®; and (5) Preventa®. Each brand had several types of pens. Samples included writing with different pens (including different pens of the same brand and different pens of different brands), writing with the same pens, horizontal and vertical orientations, and negative controls. The samples were analyzed using CONDOR imaging technology available from ChemImage Corporation, Pittsburgh, Pa.

[0059] K-means clustering was used to analyze all 70 data sets. For one data set, PLSDA took 45-60 minutes to complete. Therefore, 17 data sets were selected to include different types of data and analyzed using PLSDA. For most data sets a wavelength range of 400-720 nm, 10 nm step (33 frames) was used. For other data sets, a wavelength range of 650-750 nm, 1 nm step (101 frames) was used.

[0060] FIGS. **6**A and **6**B illustrate exemplary results for a sample created using two different pens (pen **38** and pen **28**). FIG. **6**A illustrates results after applying k-means clustering (three classes). Visual inspection of FIG. **6**A may indicate to a user that two or more inks are present in the sample based on the changes to the "8" in "2008". The distinctions are made even more clear in FIG. **6**B, which illustrates the result of applying PLSDA (three classes). The three classes used were pen **38**, pen **28**, and the background (no ink). The material in red corresponds to pen **38** and the material in green corresponds to pen **28**. Therefore, it is evident from FIG. **6**B that changes have been made to the sample regarding the year, changing "2010" to "2018".

[0061] FIGS. **7**A and **7**B illustrate exemplary results for a sample created using the same pen (pen **13**). FIG. **7**A illustrates results after applying k-means clustering (three classes). As can be seen in FIG. **7**A, two or more inks cannot be distinguished from each other. FIG. **7**B illustrates results after applying PLSDA (three classes). The three classes were pen **13**, pen **13**, and the background (no ink). As can be seen from FIG. **7**B, two or more inks cannot be distinguished from each other.

[0062] FIGS. **8**A, **8**B, and **8**C illustrate exemplary results for a sample created using different pens. FIG. **8**A illustrates results after applying k-means clustering (three classes). FIG. **8**B illustrates results after applying PLSDA (three classes). The three classes were pen **30**, pen **5**, and the background. FIG. **8**B also illustrates two regions of interest corresponding to two classes (two different inks), C**1** and C**2**. FIG. **8**C illustrates the same data as FIG. **8**B but in a different orientation. As can be seen from FIGS. **8**B and **8**C, PLSDA improves the ability to discriminate between ink types. The material in green corresponds to pen **30** and the material in red corresponds to pen **5**. Therefore, it is evident that an alteration has been made to the document, changing "31" to "34".

What is claimed is:

1. A system comprising:

a surface for placing a sample document;

an illumination source for illuminating said sample document to thereby generate a first plurality of interacted photons and a second plurality of interacted photons wherein said first and second plurality of interacted photons are selected from the group consisting of: photons reflected by said sample, photons absorbed by said sample, photons scattered by said sample, photons emitted by said sample, and combinations thereof;

a collection optics for collecting said first plurality of interacted photons and said second plurality of interacted photons;

a first detector for detecting said first plurality of interacted photons and generating a digital image representative of said sample;

at least one tunable filter through which said second plurality of interacted photons are passed to thereby generate a plurality of filtered photons;

a second detector for detecting said plurality of filtered photons and generating a hyperspectral image representative of said sample.

2. The system of claim **1** wherein said hyperspectral image comprises an image and a fully resolved spectrum unique to the material for each pixel location in said image.

3. The system of claim **1** wherein said hyperspectral image comprises a visible hyperspectral image.

4. The system of claim **1** wherein said first detector comprises a RGB camera.

5. The system of claim **1** wherein said second detector comprises a spectral camera.

6. The system of claim **5** wherein said spectral camera comprises at least one of: a charge coupled device, a complementary metal-oxide-semiconductor, an intensified charge coupled device, and combinations thereof.

7. The system of claim **1** wherein said illumination source comprises a broadband white light source.

8. The system of claim **1** wherein said collection optics comprises a zoom lens.

9. The system of claim **1** wherein said tunable filter is selected from the group consisting of: a multi-conjugate tunable filter, a liquid crystal tunable filter, acousto-optical tunable filters, Lyot liquid crystal tunable filter, Evans Split-Element liquid crystal tunable filter, Solc liquid crystal tunable filter, Ferroelectric liquid crystal tunable filter, Fabry Perot liquid crystal tunable filter, and combinations thereof.

10. The system of claim **1** further comprising a means for directing said first plurality of interacted photons to said first detector and directing said second plurality of interacted photons through said tunable filter and to said second detector.

11. The system of claim **1** wherein said illumination source may be configured to illuminate said sample at a plurality of different angles.

12. The system of claim **1** further comprising a reference database wherein said reference database comprises a plurality of reference data sets wherein each reference data set is associated with a known ink type.

13. A method comprising:

illuminating a sample document to thereby generate a first plurality of interacted photons wherein said first plurality of interacted photons are selected from the group consisting of: photons reflected by said sample, photons

absorbed by said sample, photons scattered by said sample, photons emitted by said sample, and combinations thereof;
directing said first plurality of interacted photons to a first detector;
detecting said first plurality of interacted photons at said first detector to thereby generate a digital image representative of said sample;
analyzing said digital image to thereby identify at least one region of interest of said sample;
illuminating said region of interest to thereby generate a second plurality of interacted photons wherein said second plurality of interacted photons are selected from the group consisting of: photons reflected by said sample, photons absorbed by said sample, photons scattered by said sample, photons emitted by said sample, and combinations thereof;
passing said second plurality of interacted photons through a tunable filter to thereby generate a plurality of filtered photons;
directing said plurality of filtered photons to a second detector; and
detecting said plurality of filtered photons at said second detector to thereby generate a hyperspectral image representative of said region of interest.

14. The method of claim **13** wherein said second detector comprises a spectral detector.

15. The method of claim **14** wherein said spectral detector is selected from the group consisting of: a charge coupled device, a complementary metal-oxide-semiconductor, an intensified charge coupled device, and combinations thereof.

16. The method of claim **13** further comprising: analyzing said hyperspectral image to thereby determine if two or more ink types are distinguishable in said region of interest.

17. The method of claim **16** wherein said analysis comprises visual inspection by a user.

18. The method of claim **16** wherein said analyzing comprises evaluating at least one spectra associated with at least one ink present in said region of interest.

19. The method of claim **16** further comprising:
if two or more ink types are distinguishable in said region of interest, reporting a result, and
if two or more ink types are not distinguishable in said region of interest, applying one or more chemometric techniques to said hyperspectral image.

20. The method of claim **19** wherein said chemometric technique is selected from the group consisting of: k-means clustering, partial least squares discriminate analysis, principal component analysis, and combinations thereof.

21. The method of claim **13** further comprising: analyzing said hyperspectral image to thereby determine at least one of: an alteration has been made to said region of interest and an alteration has not been made to said region of interest.

22. The method of claim **13** wherein said illuminating of at least one of said sample of document and said region of interest is accomplished using broadband white light.

23. The method of claim **13** wherein said digital image comprises a RBG image.

24. The method of claim **13** wherein said hyperspectral image comprises an image and a fully resolved spectrum unique to the material for each pixel location in said image.

25. The method of claim **13** wherein said hyperspectral image comprises a visible hyperspectral image.

26. A method comprising:
identifying at least one region of interest of a sample document wherein said region of interest comprises at least one ink type;
obtaining a hyperspectral image representative of said region of interest;
analyzing said hyperspectral image to thereby determine if two or more ink types are distinguishable in said region of interest:
if two or more ink types are distinguishable in said region of interest, reporting a result, and
if two or more ink types are not distinguishable in said region of interest, applying a first chemometric technique to said hyperspectral image to thereby generate a first processed image, wherein said chemometric technique comprises k-means clustering;
analyzing said first processed image to thereby determine if two or more ink types are distinguishable in said region of interest:
if two or more ink types are distinguishable in said region of interest, reporting a result, and
if two or more ink types are not distinguishable in said region of interest, applying a second chemometric technique to thereby generate a second processed image, wherein said chemometric technique comprises principal component analysis;
analyzing said second processed image to thereby determine if two or more ink types are distinguishable in said region of interest:
if two or more inks types are distinguishable in said region of interest, reporting a result, and
if two or more ink types are not distinguishable in said region of interest, reporting a result.

27. The method of claim **26** further comprising: if two or more inks are not distinguishable in said region of interest of said second processed image, applying partial least squares discriminate analysis.

28. The method of claim **27** wherein partial least squares discriminate analysis is applied to only ink pixels.

29. The method of claim **26** wherein analyzing said hyperspectral image comprises the steps of:
automatically identifying at least one of: background pixels, ink pixels, and combinations thereof, and
applying at least one of said first chemometric technique and said second chemometric technique to only ink pixels.

30. The method of claim **26** wherein said analysis is performed semi-automatically.

31. The method of claim **26** wherein said region of interest is identified by:
providing a sample document;
illuminating said sample document to thereby generate a first plurality of interacted photons wherein said first plurality of interacted photons are selected from the group consisting of: photons reflected by said sample document, photons absorbed by said sample document, photons scattered by said sample document, photons emitted by said sample document, and combinations thereof;
detecting said first plurality of interacted photons to thereby generate a digital image representative of said sample document;
analyzing said digital image to thereby identify at least one region of interest of said sample document.

32. The method of claim **26** wherein said hyperspectral image comprises a visible hyperspectral image.

33. The method of claim **26** wherein said analyzing comprises visual inspection by a user.

34. The method of claim **26** wherein said analyzing comprises evaluating at least one spectra associated with at least one ink present in said region of interest.

35. The method of claim **26** further comprising:

repeating the method of claim **26** for at least one other region of interest identified in said sample document.

36. A method comprising:

identifying at least one region of interest of a sample document wherein said region of interest comprises at least one ink type;

obtaining a hyperspectral image representative of said region of interest;

analyzing said hyperspectral image to thereby determine if two or more ink types are distinguishable in said region of interest:

if two or more ink types are distinguishable in said region of interest, reporting a result, and

if two or more ink types are not distinguishable in said region of interest, applying a first chemometric technique to said hyperspectral image to thereby generate a first processed image, wherein said chemometric technique comprises k-means clustering;

analyzing said first processed image to thereby determine if two or more ink types are distinguishable in said region of interest:

if two or more ink types are distinguishable in said region of interest, reporting a result, and

if two or more ink types are not distinguishable in said region of interest, applying a second chemometric technique to thereby generate a second processed image, wherein said chemometric technique comprises partial least squares discriminate analysis;

analyzing said second processed image to thereby determine if two or more ink types are distinguishable in said region of interest:

if two or more inks types are distinguishable in said region of interest, reporting a result, and

if two or more ink types are not distinguishable in said region of interest, reporting a result.

37. The method of claim **36** wherein said region of interest is identified by:

providing a sample document;

illuminating said sample document to thereby generate a first plurality of interacted photons wherein said first plurality of interacted photons are selected from the group consisting of: photons reflected by said sample document, photons absorbed by said sample document, photons scattered by said sample document, photons emitted by said sample document, and combinations thereof;

detecting said first plurality of interacted photons to thereby generate a digital image representative of said sample document;

analyzing said digital image to thereby identify at least one region of interest of said sample document.

38. The method of claim **36** wherein said hyperspectral image comprises a visible hyperspectral image.

39. The method of claim **36** wherein said analyzing comprises visual inspection by a user.

40. The method of claim **36** wherein said analyzing comprises evaluating at least one spectra associated with at least one ink present in said region of interest.

41. The method of claim **36** further comprising:

repeating the method of claim **33** for at least one other region of interest identified in said sample document.

42. The method of claim **36** wherein analyzing said hyperspectral image comprises the steps of:

automatically identifying at least one of: background pixels, ink pixels, and combinations thereof, and

applying at least one of said first chemometric technique and said second chemometric technique to only ink pixels.

43. The method of claim **36** wherein said analysis is performed semi-automatically.

44. A method comprising:

illuminating a sample document to thereby generate a first plurality of interacted photons wherein said first plurality of interacted photons are selected from the group consisting of: photons reflected by said sample, photons absorbed by said sample, photons scattered by said sample, photons emitted by said sample, and combinations thereof;

detecting said first plurality of interacted photons at a first detector to thereby generate a digital image representative of a sample document;

analyzing said digital image to thereby identify at least one region of interest of said sample document;

illuminating said region of interest to thereby generate a second plurality of interacted photons wherein said second plurality of interacted photons are selected from the group consisting of: photons reflected by said sample, photons absorbed by said sample, photons scattered by said sample, photons emitted by said sample, and combinations thereof;

detecting said second plurality of interacted photons to thereby generate a hyperspectral image representative of said region of interest;

analyzing said hyperspectral image to thereby determine if two or more ink types are distinguishable in said region of interest:

if two or more ink types are distinguishable in said region of interest, reporting a result, and

if two or more ink types are not distinguishable, applying a first chemometric technique to thereby generate a first processed image;

analyzing said first processed image to thereby determine if two or more ink types are distinguishable in said region of interest:

if two or more ink types are distinguishable in said region of interest, reporting a result, and

if two or more ink types are not distinguishable, applying a second chemometric technique to thereby generate a second processed image;

analyzing said second processed image to thereby determine if two or more ink types are distinguishable in said region of interest:

if two or more ink types are distinguishable in said region of interest, reporting a result, and

if two or more ink types are not distinguishable in said region of interest, applying a third chemometric technique to said second processed image to thereby generate a third processed image;

analyzing said third processed image to thereby determine if two or more ink types are distinguishable in said region of interest:

if two or more ink types are distinguishable in said region of interest, reporting a result, and

if two or more ink types are not distinguishable in said region of interest, reporting a result.

45. The method of claim **44** wherein said hyperspectral image comprises a visible hyperspectral image.

46. The method of claim **44** wherein said first chemometric technique is a technique selected from the group consisting of: principle component analysis, partial least squares discriminate analysis, cosine correlation analysis, Euclidian distance analysis, k-means clustering, multivariate curve resolution, band t. entropy method, mahalanobis distance, adaptive subspace detector, spectral mixture resolution, and combinations thereof.

47. The method of claim **44** wherein said second chemometric technique is selected from the group consisting of: principle component analysis, partial least squares discriminate analysis, cosine correlation analysis, Euclidian distance analysis, k-means clustering, multivariate curve resolution, band t. entropy method, mahalanobis distance, adaptive subspace detector, spectral mixture resolution, and combinations thereof.

48. The method of claim **44** wherein said third chemometric technique is selected from the group consisting of: principle component analysis, partial least squares discriminate analysis, cosine correlation analysis, Euclidian distance analysis, k-means clustering, multivariate curve resolution, band t. entropy method, mahalanobis distance, adaptive subspace detector, spectral mixture resolution, and combinations thereof.

49. The method of claim **44** further comprising:

automatically identifying at least one of: background pixels, ink pixels, and combinations thereof; and

applying at least one of said first chemometric technique, said second chemometric technique, said third chemometric, and combinations thereof to only said ink pixels.

50. The method of claim **44** wherein said analyzing comprises evaluating at least one spectra associated with at least one ink present in said region of interest.

51. The method of claim **44** wherein said analyzing comprises visual inspection by a user.

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