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(54) **TIME AND SPACE RESOLVED STANDOFF HYPERSPECTRAL IED EXPLOSIVES LIDAR DETECTOR**

(75) Inventors: **Patrick J. Treado**, Pittsburgh, PA (US); **Matthew P. Nelson**, Harrison City, PA (US); **Hugh W. Hubble, II**, Swissvale, PA (US); **Jason Neiss**, Pittsburgh, PA (US)

(73) Assignee: **ChemImage Corporation**, Pittsburgh, PA (US)

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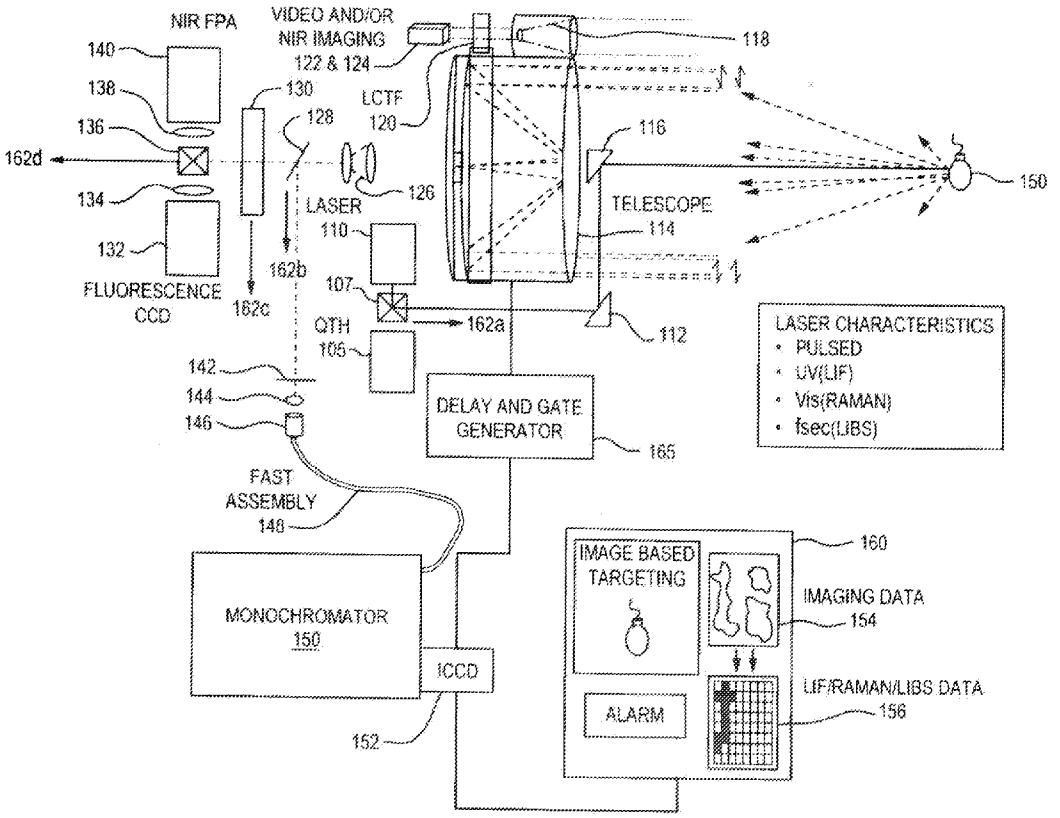
(52) **U.S. Cl.** **356/301**; 356/612

(57) **ABSTRACT**

A system and method for standoff detection of explosives and explosive residue. A laser light source illuminates a target area having an unknown sample producing luminescence emitted photons, scattered photons and plasma emitted photons. A first optical system directs light to the target area. A video capture device outputs a dynamic image of the target area. A second optical system collects photons, and directs collected photons to a first two-dimensional array of detection elements and/or to a fiber array spectral translator device which device includes a two-dimensional array of optical fibers drawn into a one-dimensional fiber stack. A spectrograph is coupled to the one-dimensional fiber stack of the fiber array spectral translator device, wherein the entrance slit of the spectrograph is coupled to the one dimensional fiber stack.



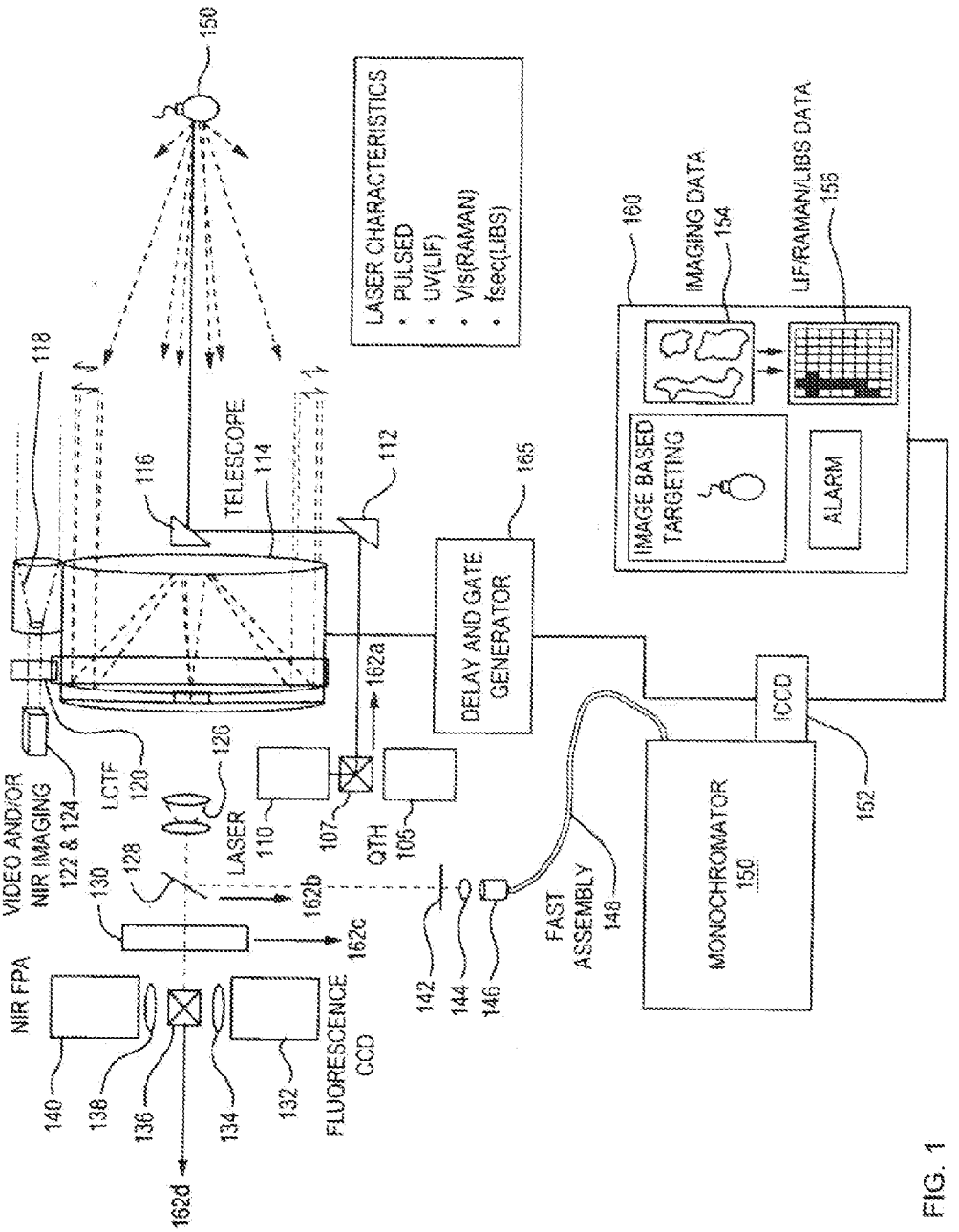

150
LASER CHARACTERISTICS
• PULSED
• UV(LIF)
• Vis(RAMAN)
• fsec(LIBS)
160
IMAGING DATA
154
LIF/RAMAN/LIBS DATA
156
IMAGE BASED TARGETING
ALARM
118
TELESCOPE
114
116
112
165
DELAY AND GATE GENERATOR
162a
ICCD
152
MONOCHROMATOR 150
FAST ASSEMBLY 148
VIDEO AND/OR NIR IMAGING 122 & 124
LCTF 120
126
LASER 110
107
QTH 106
128
130
162b
162c
142
144
146
NIR FPA
FLUORESCENCE CCD
140
138
136
134
132
162d

FIG. 1

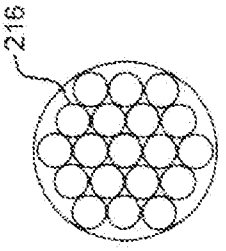

216

FIG. 2B

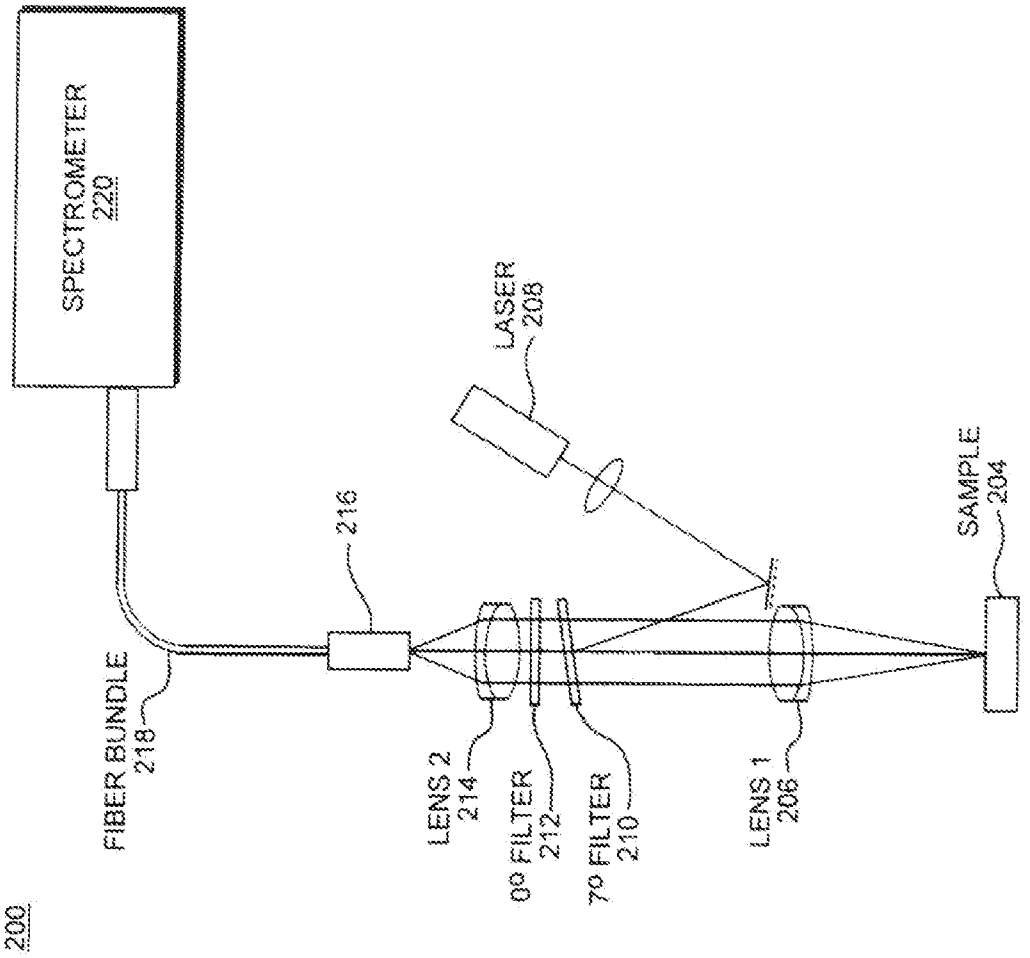

200
SPECTROMETER
220
FIBER BUNDLE
218
216
LASER
208
LENS 2
214
0° FILTER
212
70 FILTER
210
LENS 1
206
SAMPLE
204

FIG. 2A

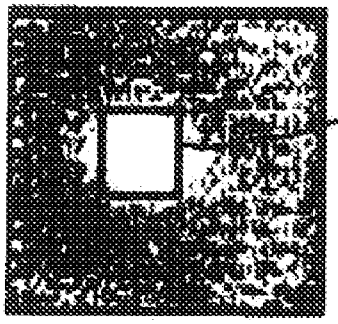


FIG. 3C

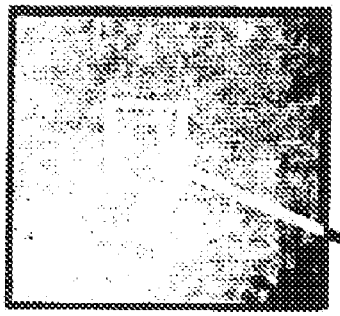


FIG. 3B

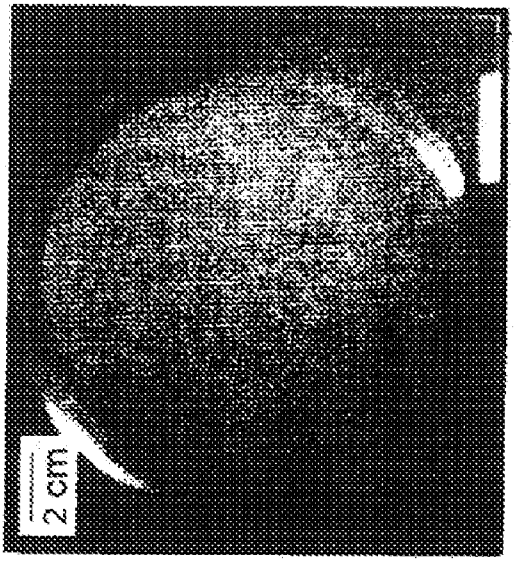


FIG. 3A

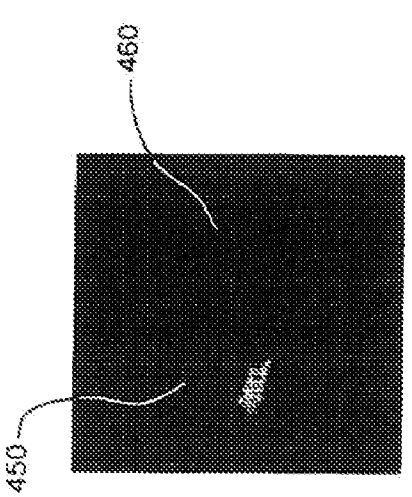


FIG. 4C

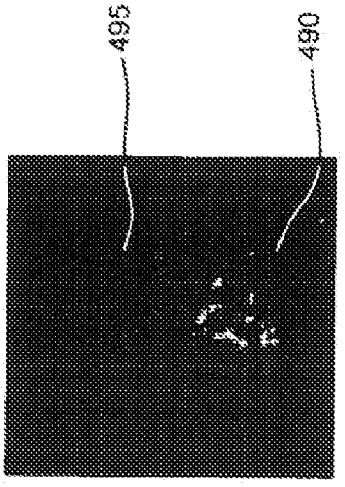


FIG. 4E

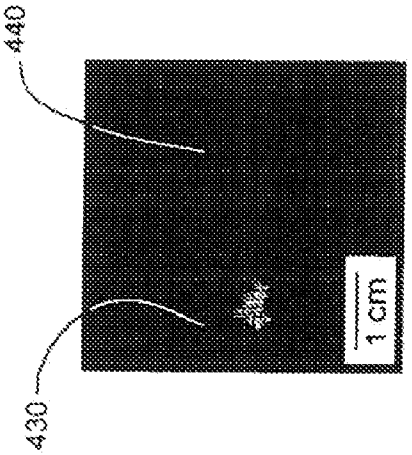


FIG. 4B

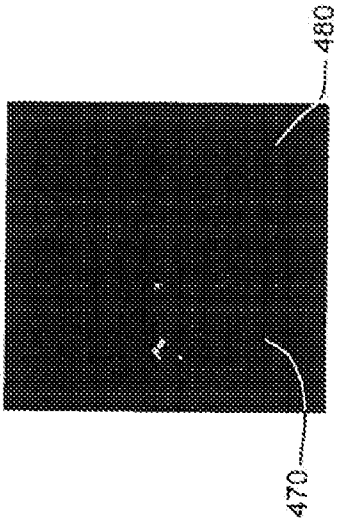


FIG. 4D

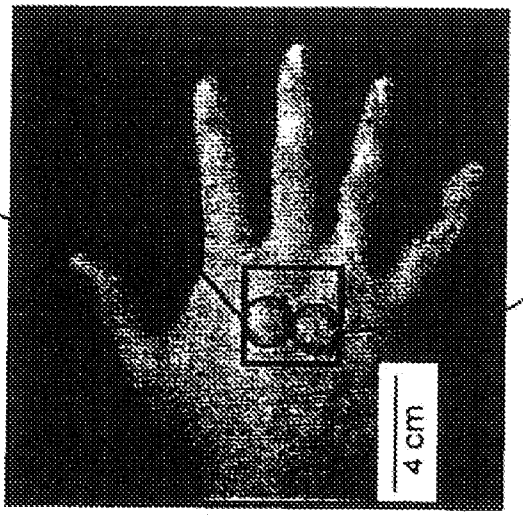


FIG. 4A

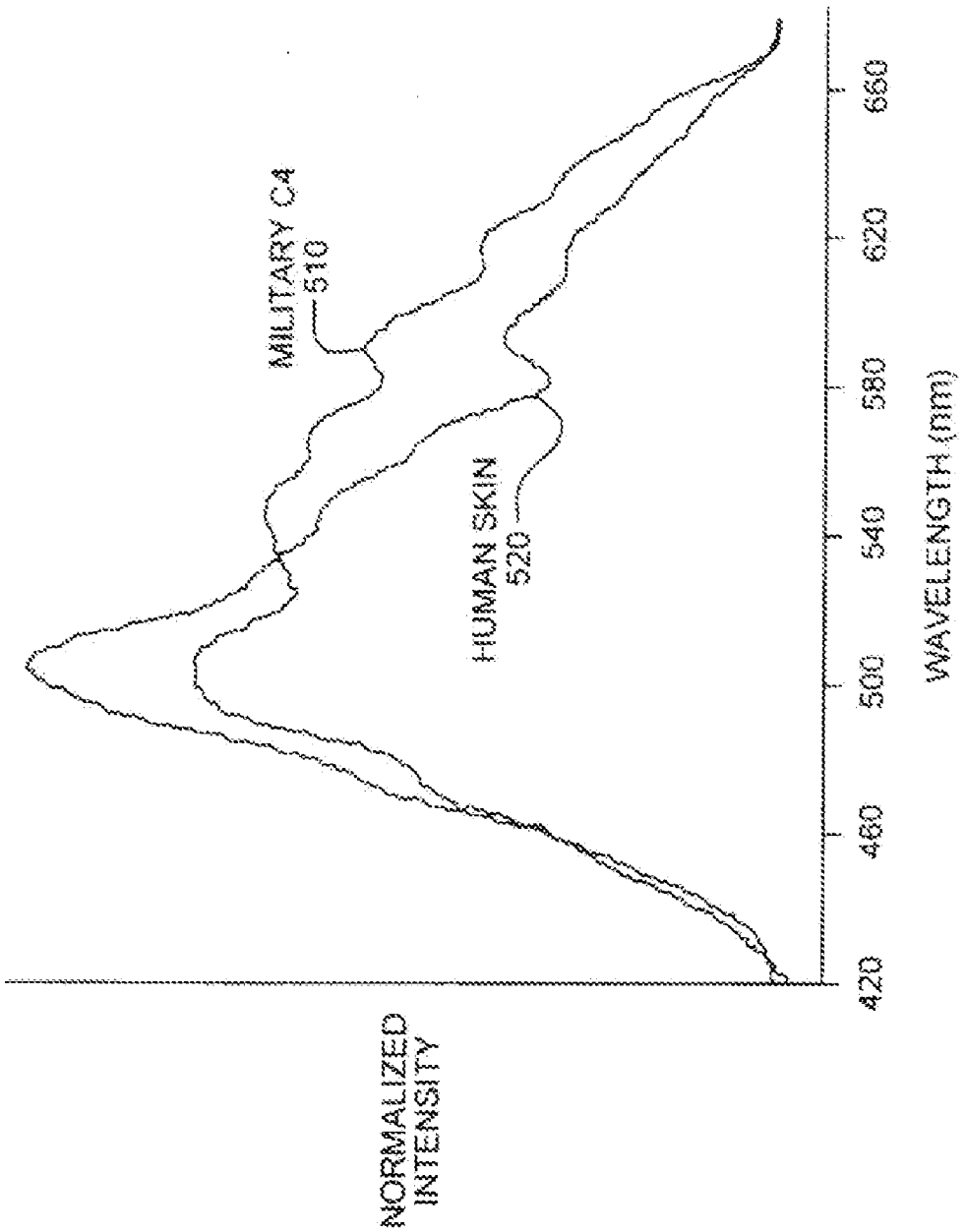

MILITARY C4
510
HUMAN SKIN
520
NORMALIZED INTENSITY
420
460
500
540
580
620
660
WAVELENGTH (nm)

FIG. 5A

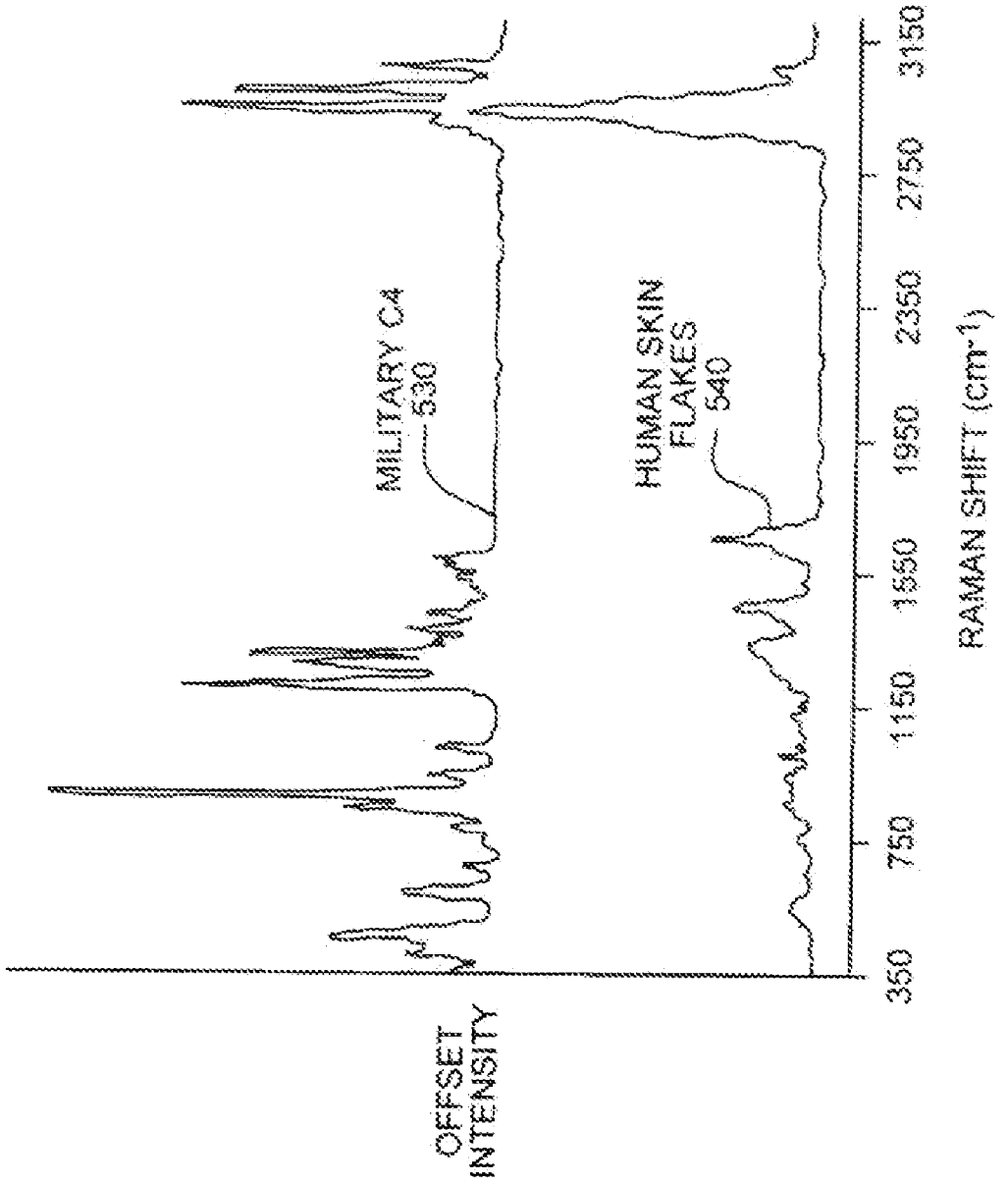

OFFSET INTENSITY
MILITARY C4
530
HUMAN SKIN FLAKES
540
350
750
1150
1550
1950
2350
2750
3150
RAMAN SHIFT (cm-1)

FIG. 5B

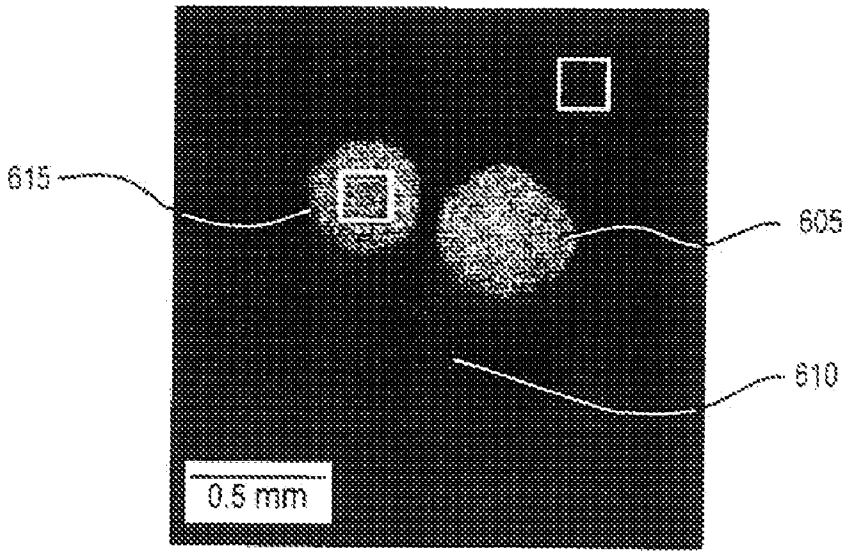

615
605
610
0.5 mm

FIG. 6A

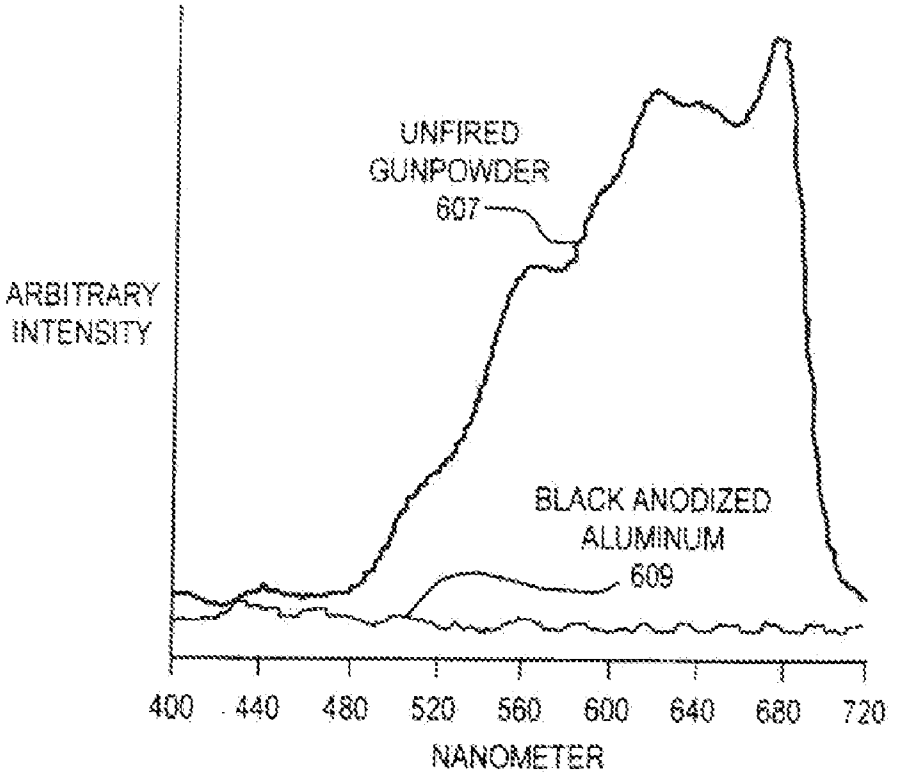

UNFIRED
GUNPOWDER
607
ARBITRARY
INTENSITY
BLACK ANODIZED
ALUMINUM
609
400
440
480
520
560
600
640
680
720
NANOMETER

FIG. 6B

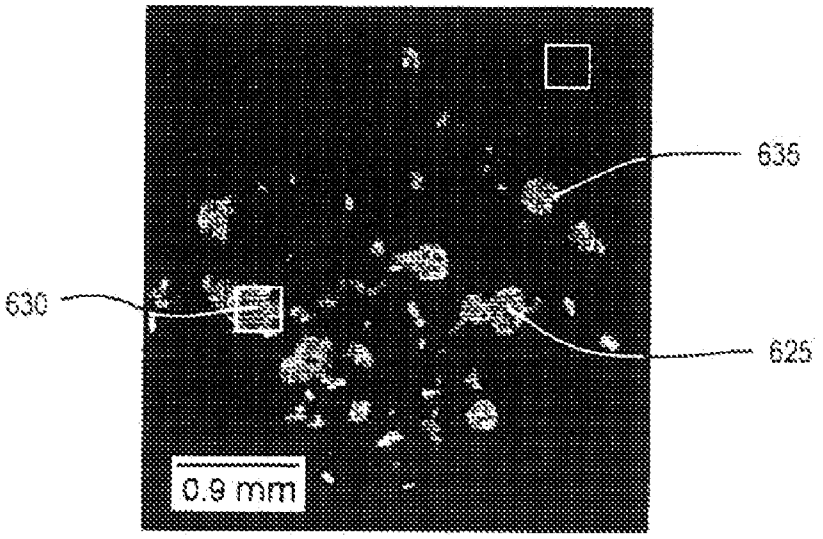

635
630
625
0.9 mm

FIG. 6C

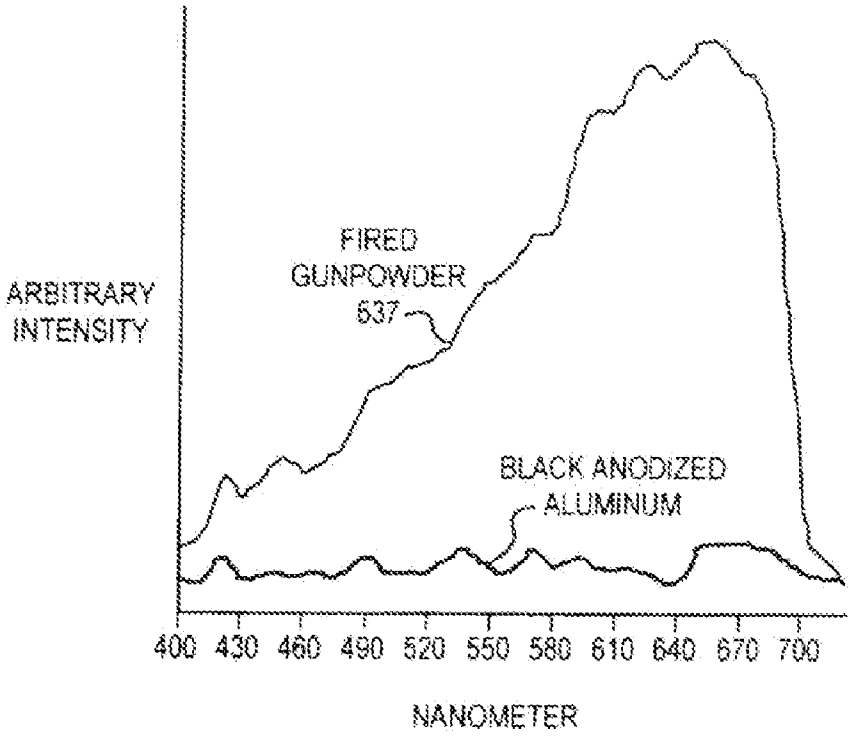

ARBITRARY INTENSITY
FIRED GUNPOWDER
637
BLACK ANODIZED ALUMINUM
400 430 460 490 520 550 580 610 640 670 700
NANOMETER

FIG. 6D

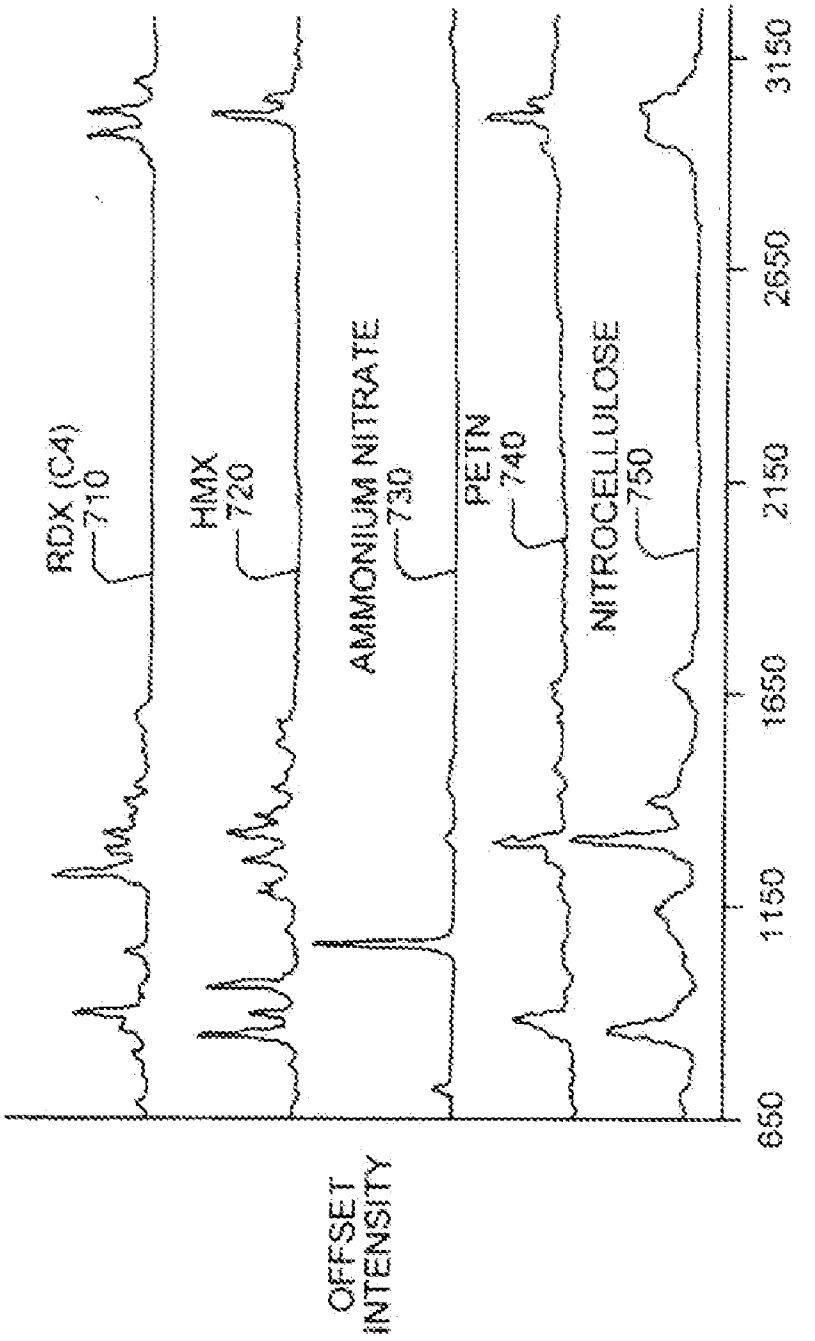

RDX (C4)
710
HMX
720
AMMONIUM NITRATE
730
PETN
740
NITROCELLULOSE
750
OFFSET INTENSITY
650
1150
1650
2150
2650
3150
RAMAN SHIFT (cm-1)

FIG. 7

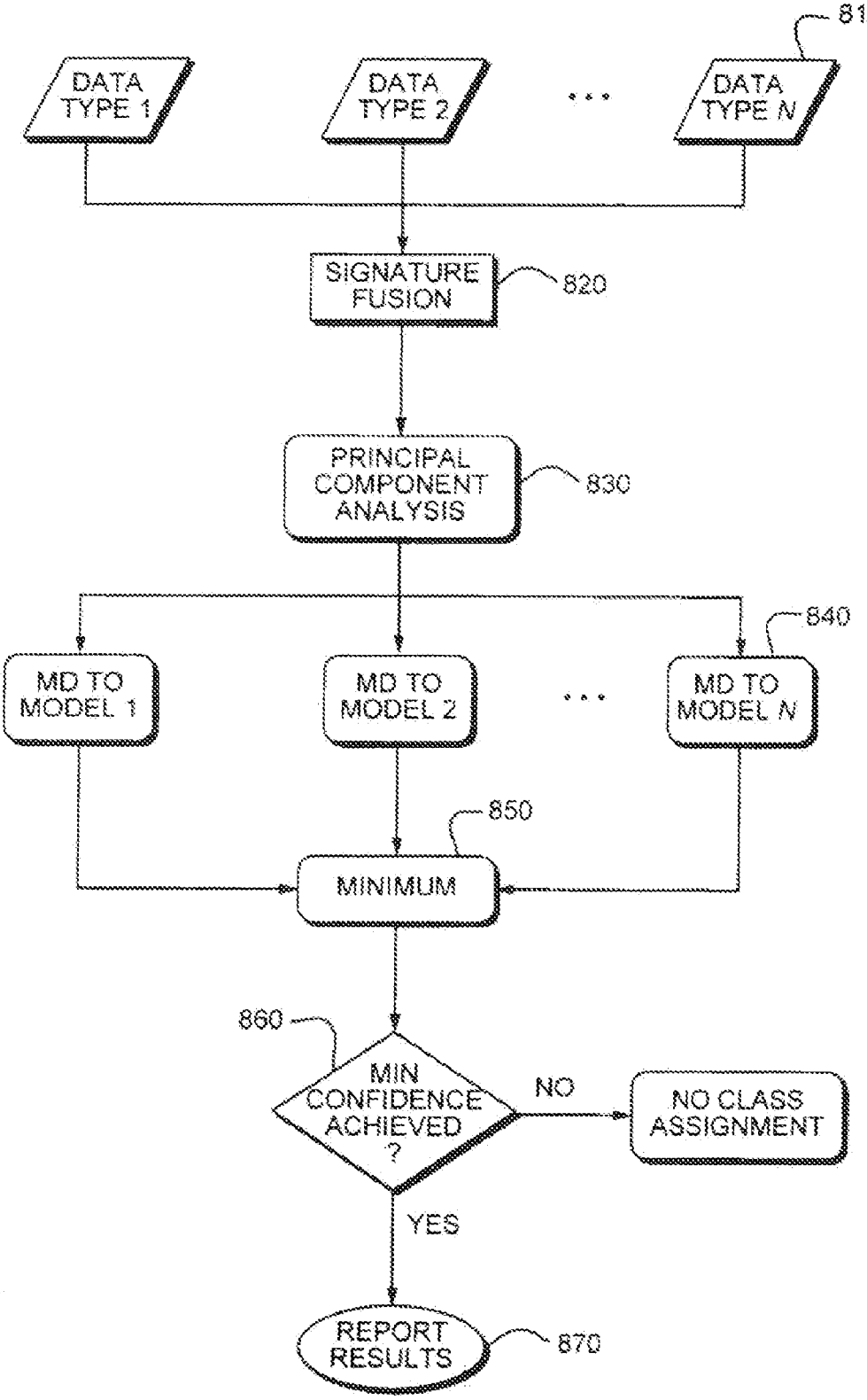

810
DATA TYPE 1
DATA TYPE 2
DATA TYPE N
SIGNATURE FUSION
820
PRINCIPAL COMPONENT ANALYSIS
830
840
MD TO MODEL 1
MD TO MODEL 2
MD TO MODEL N
850
MINIMUM
860
MIN CONFIDENCE ACHIEVED ?
NO
NO CLASS ASSIGNMENT
YES
REPORT RESULTS
870

FIG. 8

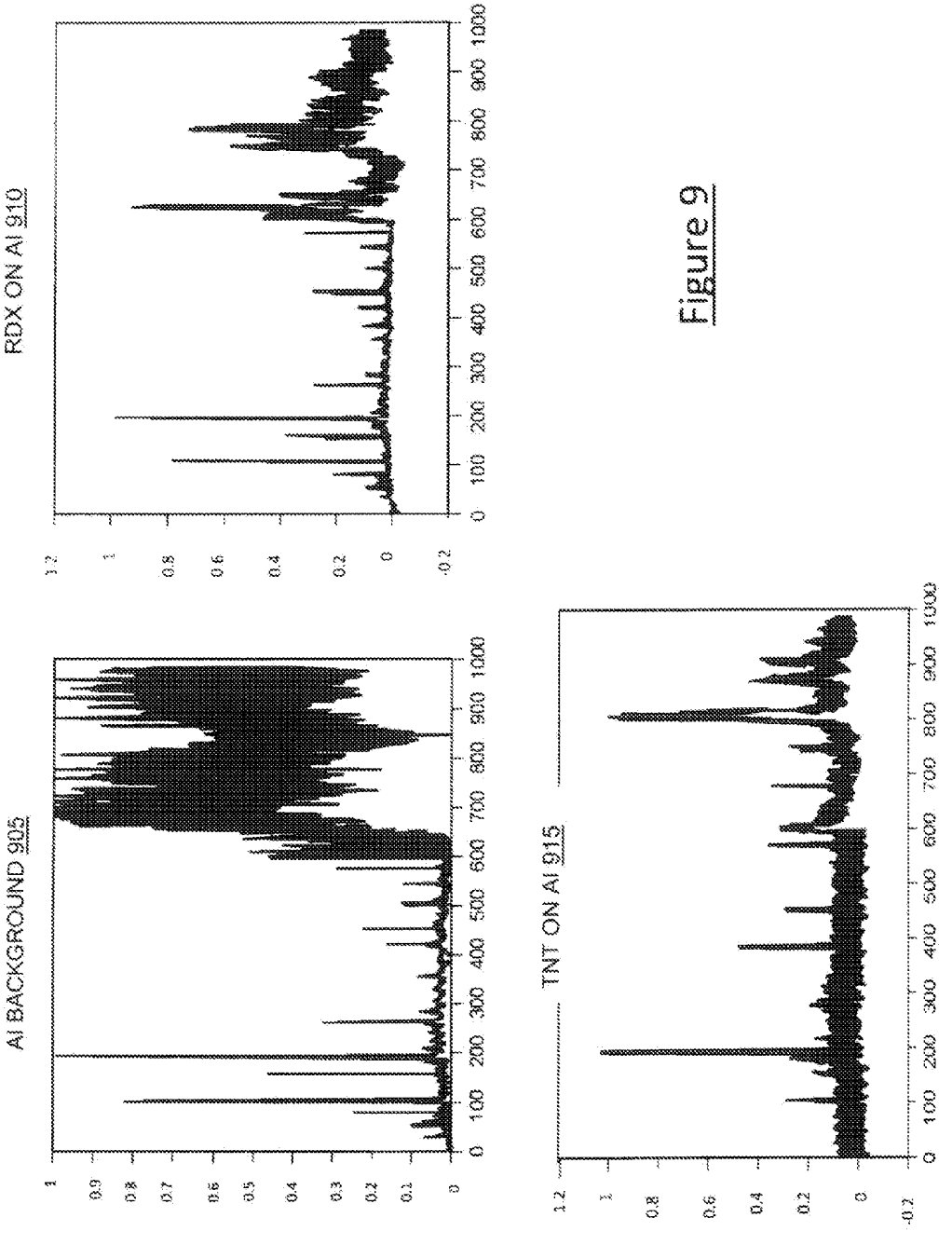


Figure 9

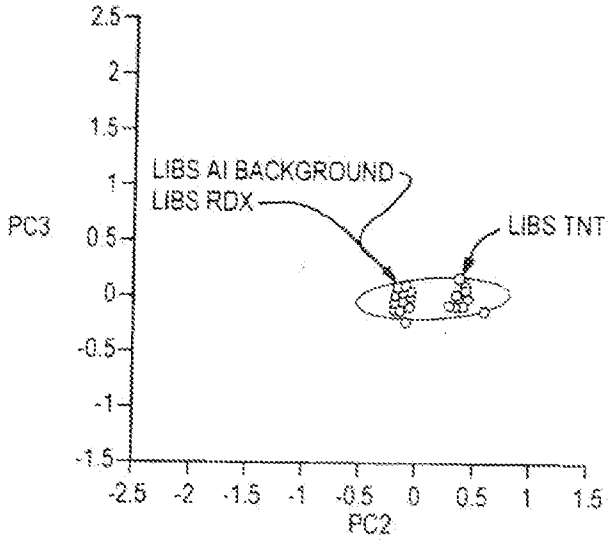


FIG. 10A

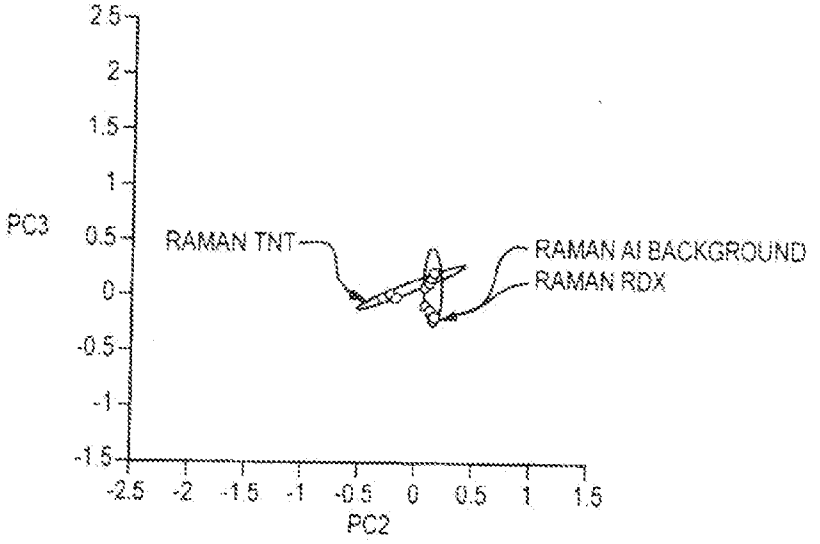


FIG. 10B

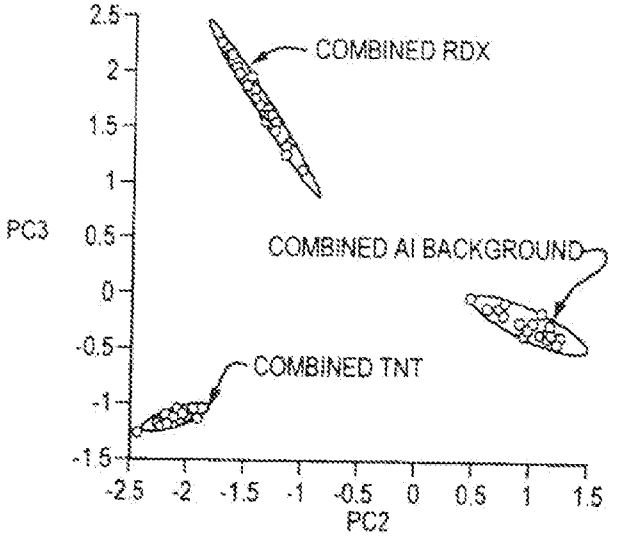


FIG. 10C

LIBS ALONE
0.45 0.23 0.30
0.40 0.25 0.35
0.05 0.10 0.85
RAMAN ALONE
0.80 0.20 0
0.10 0.79 0.11
0 0.32 0.68
FUSED
100
010
001

FIG. 11

TIME AND SPACE RESOLVED STANDOFF HYPERSPECTRAL IED EXPLOSIVES LIDAR DETECTOR

RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 11/450,149 filed on Jun. 9, 2006 entitled Time and Space Resolved Standoff Hyperspectral IED Explosives LIDAR Detection which, in turn, claims the benefit of U.S. Patent Application No. 60/699,251 filed Jul. 14, 2005 entitled SHIELD: Standoff Hyperspectral Imaging Explosives LIDAR Detector/Optical Standoff Detection of Explosive Residue, and U.S. Patent Application No. 60/786.978 filed Mar. 29, 2006 entitled Time and Space Resolved Standoff Hyperspectral IED Explosives LIDAR Detection (TSR-SHIELD). The disclosures of all of these applications are incorporated herein by reference in their entireties.

FIELD OF DISCLOSURE

[0002] This application relates generally to systems and methods for detection of explosive material and residue of explosive material.

SUMMARY

[0003] The present disclosure provides for a system and method for standoff detection of explosives and explosive residue. A laser light source is configured to illuminate a target area having an unknown sample producing luminescence emitted photons, scattered photons and plasma emitted photons from different locations on or within the unknown sample. A first optical system is optically coupled to the laser light. source to direct light to the target area having the unknown sample. A video capture device outputs a dynamic image of the target area. A second optical system collects the luminescence emitted, the scattered, and the plasma emitted photons, and directs the collected luminescence emitted photons to a first two-dimensional array of detection element. The second optical system further directs the collected scattered and plasma emitted photons to a fiber array spectral translator device. The first two-dimensional array of detection elements detects in a spatially accurate manner the luminescence emitted photons received from the second optical system and generates at least one of the following: a plurality of spatially resolved fluorescence spectra, and a plurality of spatially accurate wavelength resolved fluorescence images. The fiber array spectral translator device outputs at least one of the following received from the second optical system: the collected plasma emitted photons, and the collected scattered photons. The device includes a two-dimensional array of optical fibers drawn into a one-dimensional fiber stack so as to effectively convert a two-dimensional field of view into a curvilinear field of view. A photodiode is optically coupled to the first optical system and generates a gating signal to synchronize an acquisition time of a second two dimensional array of detection elements with a pulse width of the laser light emanating from the laser light source. A spectrograph is coupled to the one-dimensional fiber stack of the fiber array spectral translator device, wherein the entrance slit of the spectrograph is optically coupled to the one dimensional fiber stack. The spectrograph disperses the plasma emitted photons output by the fiber array spectral translator device to generate a plurality of spatially resolved Raman spectra. It also disperses the scattered photons output by the fiber array spectral translator device to generate a plurality of spatially resolved atomic spectra. The second two dimensional array of detection elements is optically coupled to the spectrograph and detects the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra produced by the spectrograph.

[0004] The present disclosure further provides for a method for detecting explosive material above ground. An above ground area is surveyed to identify a region of interest based on at least one of size, shape and color of the region of interest. The region of interest is illuminated with a plurality of photons to thereby produce emitted photons from the region of interest. The emitted photons, produced by the region of interest, are analyzed using fluorescence spectroscopy to produce at least one of the following: a plurality of spatially resolved fluorescence spectra and a plurality wavelength resolved fluorescence images. To identify a target area, the plurality of spatially resolved fluorescence spectra and the plurality wavelength resolved fluorescence images are used. The target area is illuminated with a plurality of photons to thereby produce Raman scattered photons and plasma emitted photons from the target area. Using a fiber array spectral translator device, Raman scattered photons and plasma emitted photons are collected. The device comprises a two dimensional non-linear array of optical fibers drawn into a one dimensional fiber stack that converts a two-dimensional field of view into a curvilinear field of view, wherein the one dimensional fiber stack is coupled to an entrance slit of an imaging spectrometer. The Raman scattered photons, produced by the target area, are analyzed using Raman spectroscopy to produce a plurality of spatially resolved Raman spectra. The plasma emitted photons, produced by the target area, are analyzed using laser induced breakdown spectroscopy to produce a plurality of spatially resolved atomic spectra. A fusion algorithm is applied to at least two of the following to identify one or more chemical compounds in the target area: the plurality of spatially resolved fluorescence spectra, the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra.

[0005] The present disclosure further provides for a method for detecting explosive material underground. An above ground area is surveyed to identify a region of interest based on at least one of size, shape and color of the region of interest. The region of interest is illuminated with a plurality of photons to thereby produce reflected photons from the region of interest. The reflected photons, produced by the region of interest, are analyzed using near infrared spectroscopy to produce at least one of the following: a plurality of spatially resolved near infrared spectra and a plurality wavelength resolved near infrared images. To identify a target area, the plurality of spatially resolved near infrared spectra and the plurality wavelength resolved near infrared images are used. The target areais illuminated with a plurality of photons to thereby produce Raman scattered photons and plasma emitted photons from the target area. Using a fiber array Spectral translator device, Raman scattered photons and plasma reflected photons are collected. The device comprises a two dimensional non-linear array of optical fibers drawn into a one dimensional fiber stack that converts a two-dimensional field of view into a curvilinear field of view, wherein the one dimensional fiber stack is coupled to an entrance slit of an imaging spectrometer. The Raman scattered photons produced by the target area, are analyzed using Raman spectroscopy to produce a plurality of spatially resolved Raman spec-

tra. The plasma emitted photons, produced by the target area, are analyzed using laser induced breakdown spectroscopy to produce a plurality of spatially resolved atomic spectra. A fusion algorithm is applied to at least two of the following to identify one or more chemical compounds in the target area: the plurality of spatially resolved near infrared spectra, the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] 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.

[0007] In the drawings:

[0008] FIG. **1** illustrates a system of the present disclosure;

[0009] FIGS. **2**A and **2**B illustrate a device used in a system of present disclosure;

[0010] FIGS. **3**A-**3**C illustrate a near infrared image of TNT buried in sand;

[0011] FIGS. **4**A-**4**E illustrate fluorescence images C4 on human skin;

[0012] FIGS. **5**A and **5**B illustrate fluorescence and Raman spectra of C4 and human skin flakes;

[0013] FIGS. **6**A-**6**D illustrate fluorescence images and spectra for unfired gunpowder and fired gunpowder;

[0014] FIG. **7** illustrates Raman dispersive spectra for several explosive materials;

[0015] FIG. **8** illustrates an exemplary data analysis scheme used in a method of the present disclosure;

[0016] FIG. **9** illustrates Raman and LIBS spectra for RDX and TNT on an aluminum substrate;

[0017] FIGS. **10**A-**10**C illustrate the principal component scatter plots for LIBS alone, Raman alone and the fused techniques; and

[0018] FIG. **11** illustrates the confusion matrices for LIBS alone, Raman alone and the fused techniques.

DESCRIPTION OF THE EMBODIMENTS

[0019] 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.

[0020] FIG. **1** illustrates an exemplary system **100** which may be used to carry out the methods of the present disclosure. System **100** may operate in a plurality of modes including a first order video targeting mode, a second order targeting a mode and an imaging identification mode. The video targeting mode uses a video capture device **124** for rapidly screening regions of interest. The second order targeting mode operates in a fluorescence mode, an infrared mode or a combined fluorescence and infrared mode to survey target areas for the presence of unknown materials. The imaging identification mode operates in a Raman mode and a laser induced breakdown spectroscopy ("LIBS") mode to provide greater specificity in the identification of the unknown material. The unknown material is found in a target area **150** which may be found in a region of interest including above the ground surface or below ground surface. In one embodiment, the unknown material comprises an explosive material.

[0021] With reference to FIG. **1**, system **100** includes light source to illuminate the target area having an unknown sample. The light source includes a laser light source **106** which illuminates the unknown sample with a plurality of photons to produce luminescence emitted photons, scattered photons, and plasma emitted photons from different locations on or within the unknown sample. In one embodiment, the laser light source **106** includes a femtosecond Nd.YAG pulsed light source illuminating the sample at a first wavelength of 1064 nm to produce plasma emitted photons, illuminates the sample at a second wavelength of 532 nm to produce Raman scattered and illuminates the sample at a third wavelength of 266 nm to produce luminescence emitted photons. In yet another embodiment, the laser light source **106** provides structured illumination wherein the spot size and geometry of the laser beam is controlled by control signals generated by processor **160**. In an embodiment the specifications of the laser beam include: pulse length of 7 nanoseconds (ns), beam size of 2.8 millimeters (mm), beam divergence of <6 milliradians (mrad). For a laser beam propagating in free-space, the laser beam size is dependant on distance from the laser head and can be estimated: 2.8 mm+([range](mm). times.tan(0.006)).

[0022] The femtosecond Nd:YAG laser results in femtosecond Raman scattered photons. These photons may provide enhanced S/N through the minimization of non-specific broadband fluorescence and luminescence. Most femtosecond Raman techniques thus far have been based on a pump-probe approach. Femtosecond Raman scattered photons will be measured using a conventional single pulse arrangement with appropriate filters to block broadband femtosecond response.

[0023] In addition to enhanced Raman, high intensity femtosecond lasers bring unique benefits to LIBS detection of explosives. The ultrashort LIBS plasma liberates only nanometer thicknesses of material, providing selectivity of surface contaminants from underlying material. Far less thermal plasma is created, reducing the background Planckian emission that is concurrent with species-specific spectral line emission. The unusual phenomena of self-channeling that transforms the diverging (or focused) laser beam into a .about.100.mu.m diameter self-sustaining waveguide can project breakdown energy densities to distances of a kilometer or more.

[0024] In still another embodiment, the illumination system further includes a broad band light source **105** and a beam steering mirror **107**. The broad band light source illuminates the sample in the target area with broadband light producing photons reflected from different locations on or within the unknown sample. The stirring mirror **107** functions to change the type of illumination source, from the laser light source **106** to the broad band light source **105**. The laser light source **106** and broadband light source **105** are responsive to first control signals generated by processor **160**, that control selection and operation of the laser light source **106** and the broadband light source **105**.

[0025] Referring to FIG. **1**, the first optical system is optically coupled to the laser light source **106** and the broad band light source **105**. The first optical system includes beam steering mirrors **112** and **116**, and telescope **114**. The components of the first optical system are matched to the f-number of the secondary mirror of the telescope, and expanding the laser beam to fill the secondary mirror. The laser excitation pulse propagates along the telescope's optical axis and presents a

laser spot that fills the telescope's field of view at the chosen focal point. This allows for a 180.degree. backscattering collection geometry and enables repositioning and refocusing of the telescope **114** and laser spot simultaneously.

[0026] With reference to FIG. **1**., system **100** includes a video capture device **124** that outputs a dynamic image of the target **150** in real time. The video capture device **124** provides first order targeting of explosive residues. Video is highly sensitive but has a low specificity, in that it provides a low level means of classifying objects based on morphological factors such as size, shape and color. Such first-order discrimination provides good guidance for subsequent higher order classification and detection such as LIBS spectroscopy and Raman spectroscopy/imaging. In one embodiment, the video capture device **124** uses a target scope **118** to provide the user a large field of view and zoom control for the video capture device **124**.

[0027] The video capture device **124** includes a color video CCD used as a detector. This sensor provides a high fidelity digital image, typically 480 pixel.times.640 pixel format, and a rapid frame rate, 30 Hz. The video capture device **124** may use ambient light or light from laser light source **106** to illuminate the target area. The video capture device **124** may also collect a series of small images, that are recombined into a larger, macro-image for analysis. The video capture device **124** operates in the first order targeting mode to rapidly screen objects based on the intrinsic size, shape and color properties of the particles. Regions of interest suspected to possess explosive residues are located and identified, honing in on the target area at which to conduct further analysis using LIBS/Raman imaging spectroscopy that provide greater specificity.

[0028] In another embodiment, the video capture device **124** includes a liquid crystal tunable filter **120** to sequentially filter the photons detected by the device. In yet another embodiment, the first order targeting system includes a near infrared capture device **122** that outputs an image of the target **150**. The near infrared capture device **122** uses ambient light as its light source to illuminate the target area.

[0029] The second optical system includes telescope **114**, objective **126**, beam splitter **128**, filter **130**, laser line filter **142** and lens **144**. Objective **126** collects and focuses luminescence emitted photons, reflected photons, scattered photons and plasma emitted photons and directs the collected photons to beam splitter **128**. The second optical system is responsive to second control signals that enable beam splitter **128** to direct the photons to filter **130** or the fiber array spectral translator device **148**. Beam splitter **128** directs the collected luminescence emitted photons and collected reflected photons to filter **130**. Beam splitter **128** directs the collected scattered photons and collected plasma emitted photons to fiber array spectral translator device **148**. Prior to the fiber array spectral translator device **148**, the collected scattered photons and collected plasma emitted photons pass through laser line filter **142** which filters out elastic scattered illumination light laser light source **110**. Filter **142** enables spectrally filtering of the photons at the illuminating wavelength. The collected scattered photons and collected plasma emitted photons pass through lens **144** which focuses the collected photons onto the entrance of the fiber array spectral translator device **148**.

[0030] Filter **130** is responsive to third control signals generated by processor **160**, wherein the third control signals establish predetermined wavelength bands passed by filter **130**. In one embodiment, filter **130** sequentially filters collected luminescence emitted photons, in each of a plurality of predetermined wavelength bands. In another embodiment, filter **130** sequentially filters collected reflected photons, in each of a plurality of predetermined wavelength bands. In yet another embodiment, filter **130** sequentially filters collected luminescence emitted photons and collected reflected photons in each of a plurality of predetermined wavelength hands. Filter **130** includes electro-optical tunable filters, liquid crystal tunable filter ("LCTF") or acousto-optical tunable filter ("AOTF"). The plurality of predetermined wavelength bands include specific wavelengths or ranges of wavelengths. In one embodiment, the predetermined wavelength bands include wavelengths characteristic of the sample undergoing analysis. The wavelengths that can be passed through tunable filter **130** may range from 200 nm (ultraviolet) to 2000 nm (i.e., the far infrared). The choice of tunable filter depends on the desired optical region and/or the nature of the sample being analyzed. Filter **130** includes a Fabry Perot angle tuned filter, an acousto-optic tunable filter, a liquid crystal tunable filter, a Lyot filter, an Evans split element liquid crystal tunable filter, a Sole liquid crystal tunable filter, a spectral diversity filter, a photonic crystal filter, a fixed wavelength Fabry Perot tunable filter, an air-tuned Fabry Perot tunablefilter, a mechanically-tuned Fabry Perot tunable filter, and a liquid crystal Fabry Perot tunable filter. The tunable filer is selected to operate in one or more of the following spectral ranges: the ultraviolet (UV), visible, near infrared, and mid-infrared.

[0031] Filter **130** passes photons to a two dimensional array of detection elements. In one embodiment, filter **130** passes luminescence emitted photons to a first two-dimensional array of detection elements **140** ("first detector"). The first detector **140** detects in a spatially accurate manner photons passed by the filter which were luminescence emitted from different locations on or within the unknown sample and generates at least one of plurality of spatially resolved fluorescence spectra and a plurality of spatially accurate wavelength resolved fluorescence images. In a second embodiment, filter **130** passes reflected photons to an infrared two-dimensional array of detection elements **132** ("infrared detector"). The infrared detector **132** detects in a spatially accurate manner photons passed by the filter which were reflected from different locations on or within the unknown sample and generates a plurality of spatially accurate wavelength resolved infrared images.

[0032] In another embodiment, filter **130** passes luminescence emitted photons and reflected photons to steering mirror **136**. Fourth control signals establish which detector the steering mirror **136** directs the luminescence emitted and reflected photons. In response to the fourth control signals, steering mirror **136** directs the luminescence emitted photons to lens **134** which collects and directs the luminescence emitted photons to the first detector **132**. Alternatively, steering mirror **136** directs the reflected photons to lens **138** which collects and directs the reflected photons to the infrared detector **140**, in response to the fourth control signals.

[0033] The first detector **132** and infrared detector **140** may include a digital device such as an image focal plane array ("FPA") or CCD or CMOS sensor. The optical region employed to characterize the sample of interest governs the choice of two-dimensional array detector. For example, a two-dimensional array of silicon charge-coupled device ("CCD") detection elements can be employed with visible, wavelength fluorescence for first detector **132**. Gallium arsenide (GaAs) and gallium indium arsenide (GaInAs) FPA

detectors can be employed for image analyses at near infrared wavelengths for the infrared detector **140**. The choice of such devices depends on the type of sample being analyzed. The first detector **132** detects, in a spatially accurate manner, the luminescence emitted photons passed by filter **130**. In one embodiment, each detection element in the first two-dimensional array of detection elements used to form the detection array **132**. The infrared detector **140** detects, in a spatially accurate manner, the reflected photons passed by filter **130**. In one embodiment, each detection element in the first detector **132** and the infrared detector **140** is used to form the detection array. In another embodiment, the first detector **132** and the infrared detector **140** produce digital images of the entire view of the sample as processed by filter **160**.

[0034] Fiber array spectral translator device **148** ("FAST") receives the collected scattered photons and collected plasma emitted photons. With reference to FIG. **2**, the FAST system **148** includes a first lens **206**, an illumination source **208**, a first filter **210**, a second filter **212** a second lens **214**, a first end of a fiber bundle **216** and a second end of the fiber bundle **218** which is connected to a spectrometer **150**. The first lens **206** acts as a collecting lens which focuses the illumination source onto the sample **204** and collects photons. Photons transmitted or reflected by the sample will have the same wavelength as the laser and will be blocked by filter element **212**) produced by the sample **204**. Lens **206** collimates the photons produced by the sample projecting the photons into infinity. The second lens **214** is used in combination with the first lens **206** to form images at the final focal plane of the second lens **214**. The first end of the fiber bundle **216** is comprised of a two dimensional non-linear array of fiber bundles. The second end of the fiber bundle **218** is comprised of a curvilinear array of fiber bundles wherein curvilinear may include a straight line as well as a curved line configurations. The fiber array spectral translator device **148** may have as few as six fibers providing rough spatial resolution within the sample. In another embodiment, fiber array spectral translator device **148** may have 17 collection fibers providing rough spatial resolution within the sample. Alternatively, high spatial resolution could be achieved using as many as 30,000 individual fibers.

[0035] Referring to FIG. **1**, spectrograph **150** is coupled to the fiber array spectral translator device **148**. The entrance slit of the spectrograph **150** is optically coupled to the device **148** to disperse the scattered and plasma emitted photons. For the scattered photons, spectrograph **150** disperses the photons to generate a plurality of spatially resolved Raman spectra. For the plasma emitted photons, spectrograph **150** disperses the photons to generate a plurality of spatially resolved atomic spectra.

[0036] A second two-dimensional array of detection elements **152** ("second detector") is optically coupled to the spectrograph **150** to detect the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra produced by spectrograph **150**. In one embodiment, the second two-dimensional array of detection elements **152** comprises a TE-cooled ICCD. Cooling the ICCD reduces the thermal electronic noise associated with the detector to enable the detection of the relatively weak Raman light emitted from the sample

[0037] Photodiode **165** is optically coupled to the first optical system and generates a gating signal to synchronize the acquisition time of the second two dimensional array of detection elements with a pulse width of the laser light emanating from the laser light source **110**. The photodiode **205** is positioned at the exit of the telescope **114** and triggers a delay and gate generator. This removes timing errors, which can be caused by laser Q-switch jitter, different-cable lengths and/or induced noise. The acquisition time, gate width, is then set to match the laser pulse width. Raman scattered photons are only generated while the laser pulse interacts with the sample surface, as Raman scattering has no measurable "lifetime." The delay time is then set to match the range at which data is collected, twice the distance from the sample divided by the speed of light.

[0038] Still referring to FIG. **1**, system **100** also includes at least one processor that generates a plurality of control signals. Processor **160** is coupled to and is used to control the optical devices of the system illustrated in FIG. **1**. Processor **160** generates first control signals **162***a* to control the laser light source **106**, the broad band light source **105**. Second control signals **162***b* control operation of the second optical system such that the second optical system directs the collected luminescence emitted photons to a filter and directs the collected scattered photons and the plasma emitted photons to the fiber array spectral translator device processor **150**, control beam splitter **128**. Processor **160** is also coupled to filter **130** which is responsive to third control signals **162***c* generated by processor **160**, wherein the third control signals establish predetermined wavelength bands passed by filter **130** to first detector **132** or the infrared detector **140** from different spatial locations on or within sample **100**. The fourth control signals **162***d* control. operation of steering mirror **136** such that it directs the luminescence emitted photons to the first detector **132**, and directs the reflected photons to the infrared detector **140**.

[0039] In one embodiment, system **100** operates in a luminescence emitted mode, a Raman spectroscopy mode and a laser induced break down spectroscopy mode. In another embodiment, system **100** operates in a near infrared mode, a Raman spectroscopy mode and a laser induced break down spectroscopy mode. In yet another embodiment, system **100** operates in a luminescence emitted mode, a near infrared mode, a Raman spectroscopy mode and a laser induced break down spectroscopy mode.

[0040] In the luminescence emitted mode, the first control signals control operation of the laser light source in order to produce luminescence emitted photons from different locations on or within the unknown sample. The second control signals control the operation of the second optical system such that the second optical system directs the collected luminescence emitted photons to the filter. The third control signals control operation of the filter such that the filter sequentially filters collected luminescence emitted photons, in each of a plurality of predetermined wavelength bands. The fourth control signals such that a steering mirror directs the luminescence emitted photons to the first two dimensional array of detection elements.

[0041] In the near infrared mode, the first control signals control operation of the broadband light source in order to produce photons reflected from different locations on or within the unknown sample. The second control signals control the operation of the second optical system such that the second optical system directs the collected reflected photons to the filter. The third control signals control operation of the filter such that the filter sequentially filters collected reflected photons, in each of a plurality of predetermined wavelength

bands. The fourth control signals such that a steering mirror directs the reflected photons to the infrared two dimensional array of detection elements.

[0042] In the luminescence mode and near infrared mode, the regions of interest are rapidly scanned for target areas, thereby greatly reducing the time to positively identify target analytes. Although explosive materials are not fluorescent, fluorescent contaminates/byproducts produce luminescence emitted photons. The presence of this fluorescent contamination may be used to rapidly pinpointing a target area for further investigation. Near infrared imaging provides a means for screening for surface/subsurface target areas and unknown materials.

[0043] FIGS. **3**A-**3**B illustrate the feasibility of utilizing near-infrared mode for the detection of subsurface residual explosives. TNT was placed in a Petri dish and covered with sand. The buried TNT was then placed under ChemImage's CONDOR macroscopic imaging system as illustrated in FIG. **3**A. An enlarged image of the buried TNT **310** is illustrated in FIG. **3**B. A near-IR chemical image was acquired of the area, in FIG. **3**B, where the TNT was buried, FIG. **3**C. The 1630 nm near-IR chemical image reveals the buried TNT as indicated by the boxed area **320**.

[0044] To demonstrate the feasibility of utilizing a luminescence emitted mode for the detection of residual explosives, military grade C4 explosive was placed on a human hand, FIGS. **4**A-**4**E. FIG. **4**A illustrates an image of thehand obtained with ChemImage's CONDOR macroscopic imaging system. A fluorescence chemical image was acquired from an area on the skin containing two locations encircled by ink marks—one area **410** containing C4, and one area **420** without C4, FIG. **4**A. Fluorescence images were collected immediately after the C4 was placed on the skin FIG. **4**B, following a wipe, FIG. **4**C, and after the hand was washed with soap and water, FIG. **4**C. Using fluorescence imaging, even trace levels of C4 were located in area **470** compared to area **480**, after the hand was washed with soap and water. These results are striking and suggest significant sensitivity to trace levels of C4, or more likely, explosives packaging materials. FIG. **5**A illustrates the fluorescence spectrum of C4, **510** compared to the fluorescence spectrum of human skin **520**. As illustrated in FIG. **5**B, the Raman spectrum of C4, **530** is also significantly different from that of human skin **540**, suggesting that Raman spectroscopy may also provide a sensitive tool for the detection of trace explosive material.

[0045] With reference to FIGS. **6**A-**6**D, the ability of fluorescence imaging to enhance the visualization of unfired gunpowder and fired gunpowder is illustrated. FIG. **6**A illustrates a fluorescence image of unfired gun powder, where the unfired gunpowder is located in areas **605**, **610** and **615**. The fluorescence spectrum of the unfired gunpowder **607** was obtained from area **605**, and the fluorescence spectrum **609** of the anodized aluminum background was obtained from area **620**, FIG. **6**B. FIG. **6**C illustrates a fluorescence image of fired gun powder, where the fired gunpowder is located in areas **625**, **630** and **635**. The fluorescence spectrum **637** of the fired gunpowder was obtained from area **630**, FIG- **6**D.

[0046] In the Raman mode, the first control signals control operation of the laser light source in order to produce scattered photons from different locations on or within the unknown sample. The second control signals control the operation of the second optical system such that the second optical system directs the collected scattered photons to the fiber array spectral translator device.

[0047] The capability to provide highly specific signatures from representative explosive materials in the Raman mode is illustrated in FIG. **7**. The dispersive Raman spectra, include RDX (C4) **710**, HMX **720**, Ammonium nitrate **730**, PETN **740**, and nitrocellulose **750**. Each material type exhibits a molecular-specific fingerprint signature. The Raman spectra are inherently richer in information

[0048] In the Raman mode, Raman imaging spectroscopy is used as a tool for molecular identification. Explosive materials have strong, unique Raman spectra that are "fingerprints" of the vibrational spectrum of the molecule. This mode differentiates between two very similar molecules, and to differentiate between a target analyte and its matrix. Using the fiber array translator device provides low pixel fidelity spatially resolved Raman dispersive spectral images and improved reliability of detecting target analytes from a deposited mixture of particles.

[0049] In the LIBS mode, the first control signals control operation of the laser light source in order to produce plasma emitted photons from different locations on or within the unknown sample. The second control signals control the operation of the second optical system such that the second optical system directs the collected plasma emitted photons to the fiber array spectral translator device.

[0050] System **100** further includes instructions executable by at least one processor that applies a fusion algorithm to two or more data types including spatially resolved fluorescence spectra, the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra, in order to identify the unknown sample. In one embodiment, the multiple data types are fused and then searched relative to a signature library or Data Fusion Then Search. As illustrated in FIG. **8**, the multiple data types are fused by concatenating the corresponding multiple spectra into combined data, **820**. Principal Component Analysis was then performed on the combined data to identify the important features, **830**. Models of the class data were then created, using a similarity metric, **840**. The model data are examined to determine if a minimum confidence is achieved, **860**. If a minimum confidence is achieved, the results are reported, **870**. If a minimum confidence is not achieved, no class assignment is made. In one embodiment, the minimum confidence value may range from 0.70 to 0.95. In another embodiment, the minimum confidence value ranges from 0.8 to 0.95. In yet another embodiment, the minimum confidence value ranges from 0.90 to 0.95.

[0051] Results from the Data Fusion Then Search (DFTS) approach are shown in FIG. **9**. Raman and LIBS spectra were obtained for aluminumsubstrate, RDX on the aluminum substrate and TNT on the substrate. At least ten (10) Raman and LIBS spectra were obtained for material. The spectra were fused and evaluated using confusion matrices. The fusion was performed by concatenating the corresponding LIBS and Raman spectrainto combined data. Principal Component Analysis was then performed on the combined data to identify the important features. Models of the class data were then created, using Mahalanobis distance as the metric. The training data were sent hack through these models resulting in confusion matrices that quantify the power of the classifier. A perfect classifier results in 1's along the diagonal and 0's in the off-diagonal terms.

[0052] FIG. **10** illustrates the principal component scatter plots demonstrating that the DFTS sensor data fusion results exhibit improved performance relative to LIBS operating

alone or Raman operating alone. Better performance is evident from the J3 criterion calculated for the combined (fusion) results compared to Raman and LIBS operating alone. The J3 criterion is a measure of discrimination and is a ratio of interclass to intraclass variability. A high J3 value reflects greater discrimination between materials. LIBS operating alone had a J3 value of 2.736426, FIG. **10**A. Raman operating alone had a J3 value of 4.759002, FIG. **10**B. The combined results, FIG. **1**C, had a J3 value of 192.306435, a factor of 2.times. greater J3 value than each of the LIBS or Raman data alone. Another measure of improved discrimination performance is the diagonal terms from the confusion matrices, FIG. **11**. Test data indicated that the fused LIBS and Raman data produced superior confusion matrices relative to the LIBS or Raman data taken individually through the same process.

[0053] In the case of mixture unknown, the search is performed using a spectral unmixing metric that compares a plurality of spectra for the unknown to library spectra. A spectral unmixing metric is disclosed in U.S. patent application Ser. No. 10/812,233 entitled "Method for Identifying Components of a Mixture via Spectral Analysis," filed Mar. 29, 2004 which is incorporated herein by reference in its entirety.

[0054] The system of the present disclosure may be used to identify unknown materials located above the ground. An above ground area is surveyed to identify a region of interest based on at least one of size, shape and color of the region of interest. The region of interest is illuminated with a plurality of photons producing emitted photons from the region of interest. The emitted photons, produced by the region of interest, are analyzed using fluorescence spectroscopy to produce at least one of the following: a plurality of spatially resolved fluorescence spectra and a plurality Wavelength resolved fluorescence images. To identify a target area, one or both of the plurality of spatially resolved fluorescence spectra and the plurality wavelength resolved fluorescence images are used. The target area is then illuminated with a plurality of photons producing Raman scattered photons and plasma emitted photons from the target area. Using a fiber array spectral translator device, Raman scattered photons and plasma emitted photons produced by the target area are collected. The fiber array spectral translator device comprises a two dimensional non-linear array of optical fibers drawn into a one dimensional fiber stack that converts a two-dimensional field of view into a curvilinear field of view, wherein the one dimensional fiber stack is coupled to an entrance slit of an imaging spectrometer. The Raman scattered photons, produced by the target area, are analyzed using Raman spectroscopy to produce a plurality of spatially resolved Raman spectra. The plasma emitted photons, produced by the target area, are analyzed using laser induced breakdown spectroscopy to produce a plurality of spatially resolved, atomic spectra. To identify one or more chemical. compounds in the target area, a fusion algorithm is applied to at least two of the following: the plurality of spatially resolved fluorescence spectra, the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra.

[0055] The system of the present disclosure may be used to identify unknown materials located under the ground. A below ground area is surveyed to identify a region of interest based on at least one of size, shape and color of the region of interest. The region of interest is illuminated with a plurality of photons producing reflected photons from the region of interest. The reflected photons, produced by the region of interest, are analyzed using near infrared spectroscopy to produce a plurality wavelength resolved near infrared images. To identify a target area, one or both of the plurality of spatially resolved near infrared spectra and the plurality wavelength resolved near infrared images are used. The target area is then illuminated with a plurality of photons producing Raman scattered photons and plasma emitted photons from the target area. Using a fiber array spectral translator device, Raman scattered photons and plasma emitted photons produced by the target area are collected. The fiber array spectral translator device comprises atwo dimensional non-linear array of optical fibers drawn into a one dimensional fiber stack that converts a two-dimensional field of view into a curvilinear field of view, wherein the one dimensional fiber stack. is coupled to an entrance slit of an imaging spectrometer. The Raman scattered photons, produced by the target area, are analyzed using Raman spectroscopy to produce a plurality of spatially resolved Raman spectra. The plasma emitted photons, produced by the target area, are analyzed using laser induced breakdown spectroscopy to produce a plurality of spatially resolved atomic spectra. To identify one or more chemical compounds in the target area, fusion algorithm is applied to at least two of the following: the plurality of spatially resolved fluorescence spectra, the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra.

[0056] 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 preferred embodiments of the disclosure, it is noted that other variations and modification will be apparent to those skilled in the art, and may be made without departing from the spirit or scope of the disclosure.

What is claimed is:

1. A method comprising:

(a) surveying an area to identify a region of interest comprising an unknown material wherein said identification of said region of interest is based on at least one of size, shape and color of said region of interest;

(b) illuminating the region of interest with a plurality of photons to thereby produce photons reflected from different locations on or within the unknown sample in said region of interest;

(c) collecting said reflected photons Using short wave infrared spectroscopy to produce at least one of the following: a plurality of infrared spectra and a plurality of wavelength resolved infrared images; and

wherein steps (a)-(c) are performed at a standoff distance from said unknown material.

2. The method of claim **1** wherein said a plurality of spatially resolved infrared spectra comprise short wave infrared spectra and said plurality wavelength resolved infrared images comprise short wave infrared images.

3. The method of claim **1** wherein said surveying is achieved using a telescope optics.

4. The method of claim **1** wherein said illuminating is achieved using a telescope optics.

5. The method of claim **1** wherein said collecting is achieved using a telescope optics.

6. The method of claim **1** further comprising analyzing at least one of said plurality of infrared spectra and said plurality of wavelength resolved infrared images to thereby identify said unknown material.

7. The method of claim **1** wherein said surveying comprises using a video capture device.

8. The method of claim **7** wherein said video capture device outputs a dynamic image of said area.

9. The method of claim **1** wherein said unknown material comprises an explosive material.

10. The method of claim **1** wherein said unknoWn material comprises an explosive residue.

11. The method of claim **1** wherein said unknown material comprises a chemical compound.

12. The method of claim **1** wherein said area is surveyed at a standoff distance.

13. The method of claim **1** wherein said region of interest is illuminated at a standoff distance.

14. The method of claim **1** wherein said area is selected from the group consisting of: an above ground area, a below ground area, and combinations thereof.

15. The method of claim **1** further comprising passing said reflected photons through a tunable filter selected from the group consisting of: a liquid crystal tunable filer, an electro-optical tunable filter, an acusto-optical tunable filter, and combinations thereof.

16. The method of claim **15** wherein said filter filters said reflected photons in a each of a plurality of predetermined wavelength bands.

17. The method of claim **1** wherein said region of interest is illuminated using broadband light.

18. The method of claim **1** further comprising analyzing at least one of said a plurality of spatially resolved infrared spectra and a plurality wavelength resolved infrared images to thereby determine a target area.

19. The method of claim **18** wherein said target area comprises at least one of the following: an above ground area and a below ground area.

20. The method of claim **18** further comprising:

illuminating said target area with a plurality of photons to thereby produce Raman scattered photons and plasma emitted photons from the target area;

collecting, via a fiber array spectral translator device, Raman scattered photons and plasma emitted photons produced by the target area, wherein said device comprises a two dimensional array of optical fibers drawn into a one dimensional fiber stack so as to effectively convert a two-dimensional field of view into a curvilinear field of view;

analyzing the Raman scattered photons, produced by the target area, using Raman spectroscopy to produce a plurality of spatially resolved Raman spectra;

analyzing the plasma emitted photons, produced by the target area, using laser induced breakdown spectroscopy to produce a plurality of spatially resolved atomic spectra; and

applying a fusion algorithm to at least two of the following to identify one or more chemical compounds in the target area: the plurality of spatially resolved infrared spectra, the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra.

21. A method comprising:

(a) surveying an area to identify a region of interest comprising an unknown material wherein said identification of said region of interest is based on at least one of size, shape and color of said region of interest;

(b) illuminating the region of interest with a plurality of photons to thereby produce photons reflected from different locations on or within the unknown sample in said region of interest;

(c) collecting said reflected photons using infrared spectroscopy to produce at least one of the following: a plurality of spatially resolved infrared spectra and a plurality wavelength resolved infrared images;

(d) analyzing at least one of said a plurality of spatially resolved infrared spectra and a plurality wavelength resolved infrared images to thereby determine a target area;

(e) illuminating said target area with a plurality of photons to thereby produce Raman scattered photons and plasma emitted photons from the target area;

(f) collecting, via a fiber array spectral translator device, Raman scattered photons and plasma emitted photons produced by the target area, wherein said device comprises a two dimensional array of optical fibers drawn into atone dimensional fiber stack so as to effectively convert a two-dimensional field of view into a curvilinear field of view;

(g) analyzing the Raman scattered photons, produced by the target area, using Raman spectroscopy to produce a plurality of spatially resolved Raman spectra;

(h) analyzing the plasma emitted photons, produced by the target area, using laser induced breakdown spectroscopy to produce a plurality of spatially resolved atomic spectra; and

(i) applying a fusion algorithm to at least two of the following to identify one or more chemical compounds in the target area: the plurality of spatially resolved infrared spectra, the plurality of spatially resolved Raman spectra and the plurality of spatially resolved atomic spectra, wherein steps (a)-(i) are performed at a standoff distance from said unknown material.

22. The method of claim **21** wherein said surveying is achieved using a telescope optics.

23. The method of claim **21** wherein said illuminating of said region of interest is achieved using a telescope optics.

24. The method of claim **21** wherein said reflected photons are collected using a telescope optics.

25. The method of claim **21** wherein said area comprises at least one of: an above ground area and a below ground area.

26. The method of claim **21** wherein said unknown material comprises at least one of an explosive material, an explosive residue, and a chemical compound.

27. The method of claim **21** wherein said surveying comprises using a video capture device.

28. The method of claim **27** wherein said video capture device outputs a dynamic image of said area.

29. The method of claim **18** further comprising:

illuminating said target area with a plurality of photons to thereby produce Raman scattered photons from the target area;

collecting said Raman scattered photons using Raman spectroscopy to produce at least one of following: a plurality of spatially resolved Raman spectra, a plurality of wavelength resolved Raman images, and combinations thereof.

30. The method of claim **29** further comprising analyzing at least one of said plurality of spatially resolved Raman spectra and said plurality of wavelength resolved Raman images to thereby identify said unknown materials.

31. The method of claim **29** further comprising collecting said Raman scattered photons via a fiber array spectral translator device, wherein said device comprises a two dimensional array of optical fibers drawn into a one dimensional fiber stack so as to effectively convert a two dimensional field of view into a curvilinear field of view.

32. The method of claim **21** wherein said a plurality of spatially resolved infrared spectra comprise short wave infrared spectra and said plurality wavelength resolved infrared images comprise short wave infrared images.

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