US006832003B2

(12) **United States Patent**
McGrew

(10) **Patent No.: US 6,832,003 B2**
(45) **Date of Patent: *Dec. 14, 2004**

(54) **METHOD AND APPARATUS FOR READING AND VERIFYING HOLOGRAMS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/368,120**

(22) Filed: **Feb. 14, 2003**

(65) **Prior Publication Data**

US 2003/0152274 A1 Aug. 14, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/881,409, filed on Jun. 13, 2001, now Pat. No. 6,535,638, which is a continuation of application No. 09/224,260, filed on Dec. 31, 1998, now Pat. No. 6,263,104.

(51) **Int. Cl.**^{7} **G06K 9/76**

(52) **U.S. Cl.** **382/210**; 359/559; 250/550; 369/103; 235/457

(58) **Field of Search** 382/205, 207, 382/209, 210, 218, 224, 254, 220, 276, 212, 260, 263, 274, 168; 235/457, 454, 462.42, 462.07, 462.11; 369/103; 359/561, 29, 559; 244/3.17; 707/6; 250/550, 559.11

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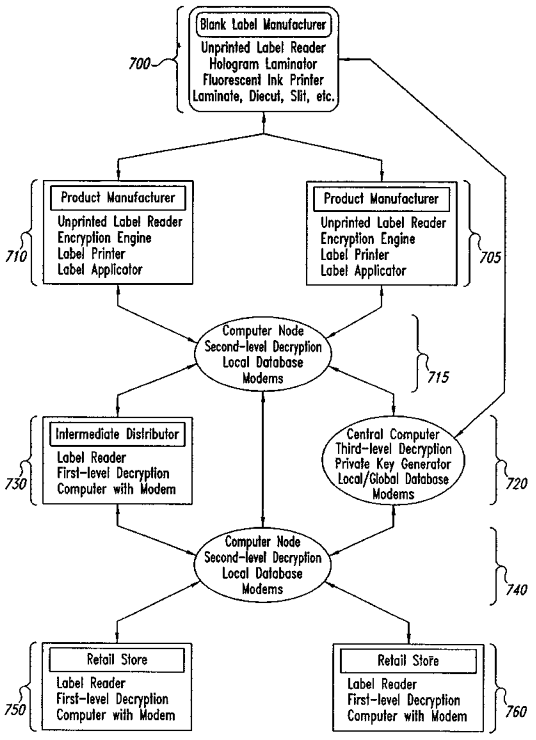
(57) **ABSTRACT**

A system and method for reading the information stored in holograms and other diffractive objects. The information is read by analyzing the diffraction pattern produced when a laser beam is focused onto a small spot on the object and scanned across the object.

5 Claims, 6 Drawing Sheets



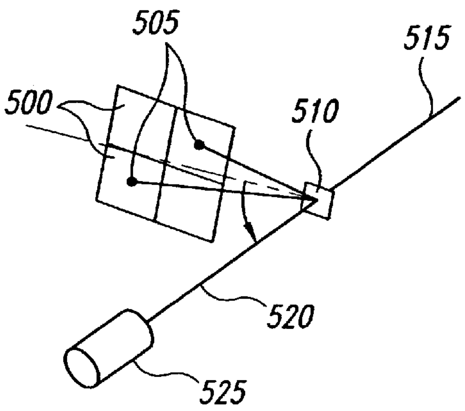


Fig. 1A
(Prior Art)

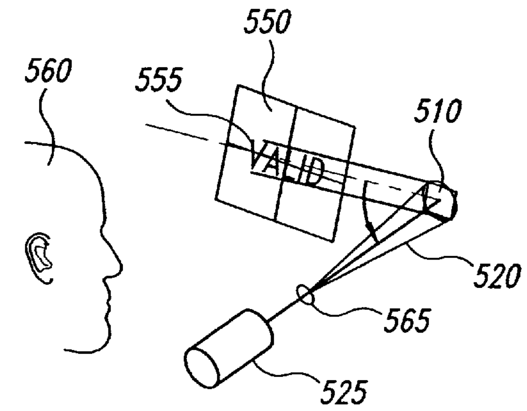


Fig. 1B
(Prior Art)

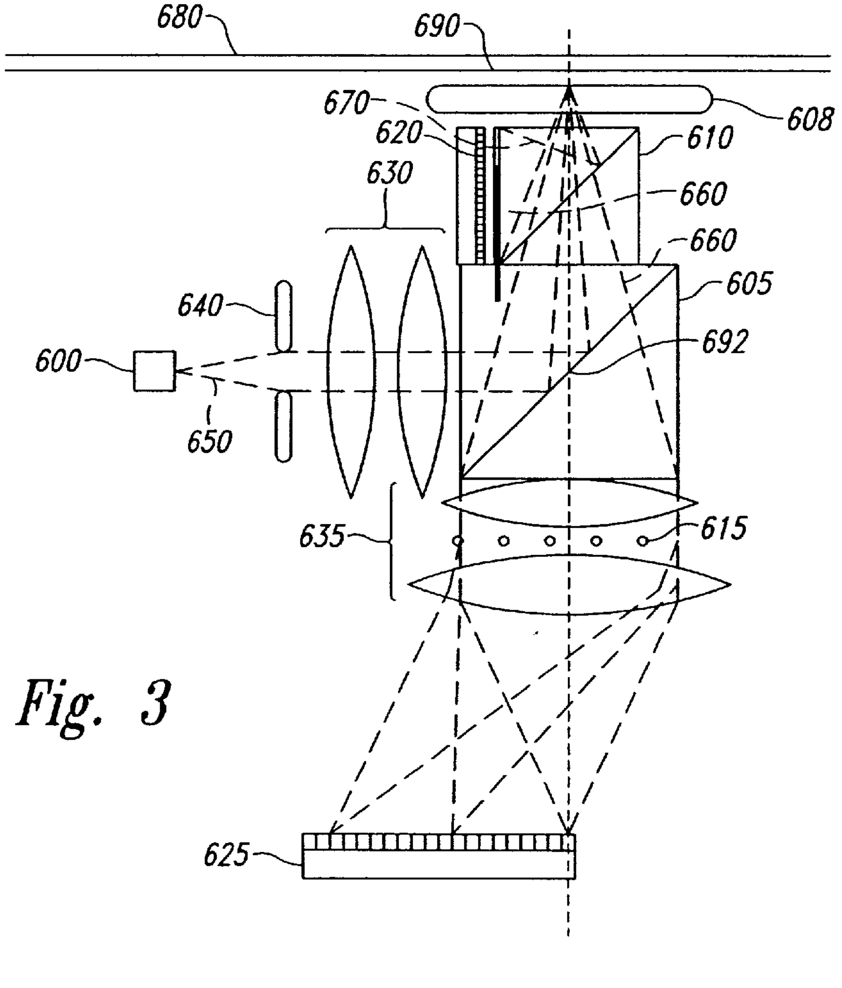


Fig. 3

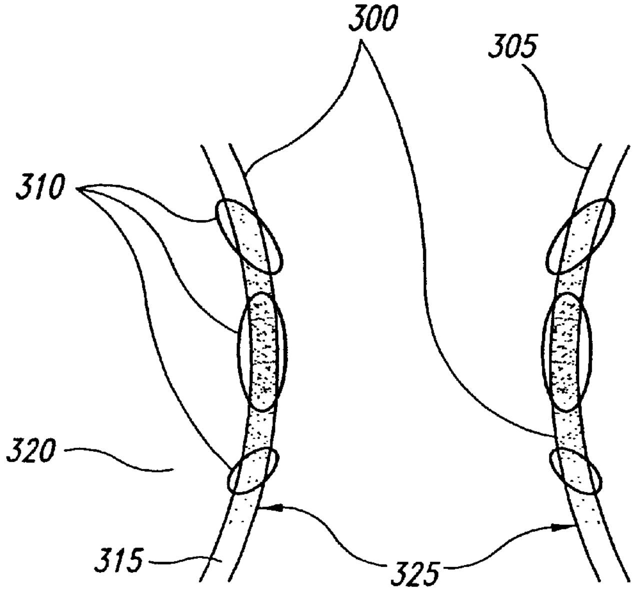

300
305
310
320
315
325

Fig. 2A

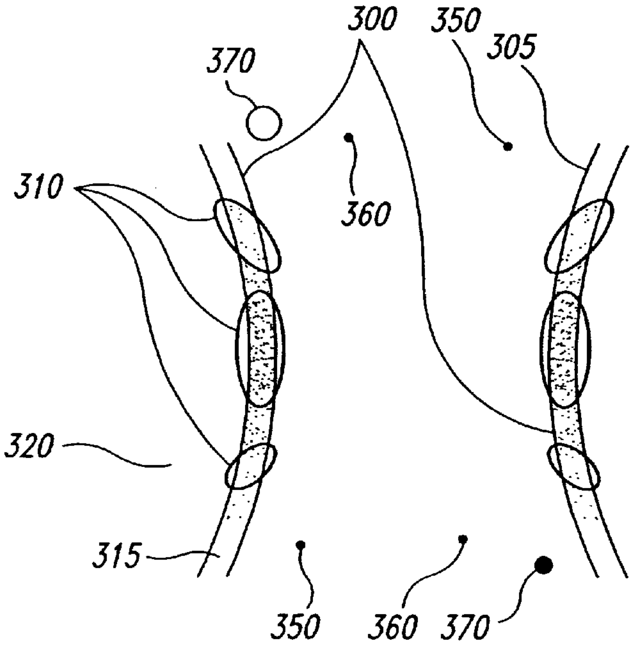

300
350
305
370
310
360
320
315
350
360
370

Fig. 2B

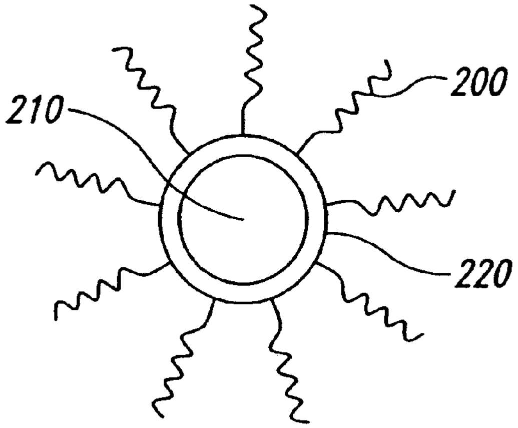

200
210
220

Fig. 4

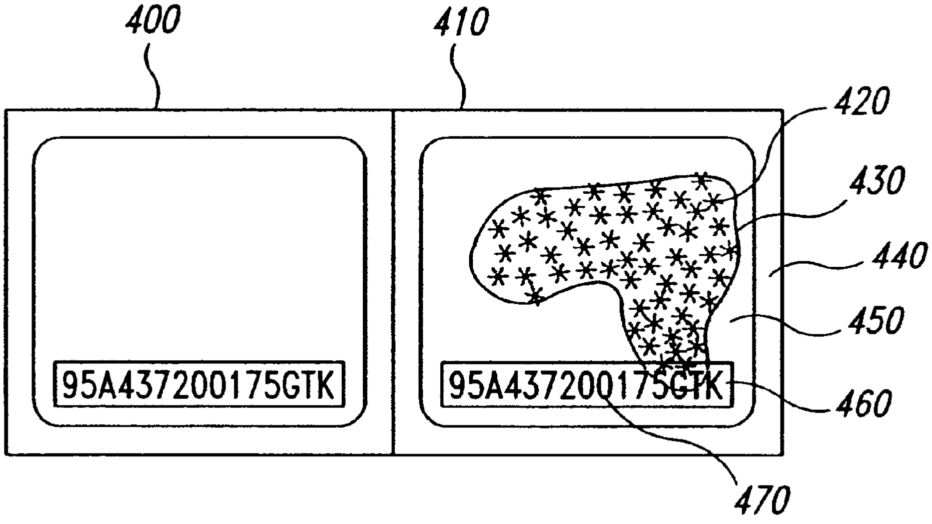

400
410
420
430
440
450
460
470
95A437200175GTK
95A437200175GTK

Fig. 5

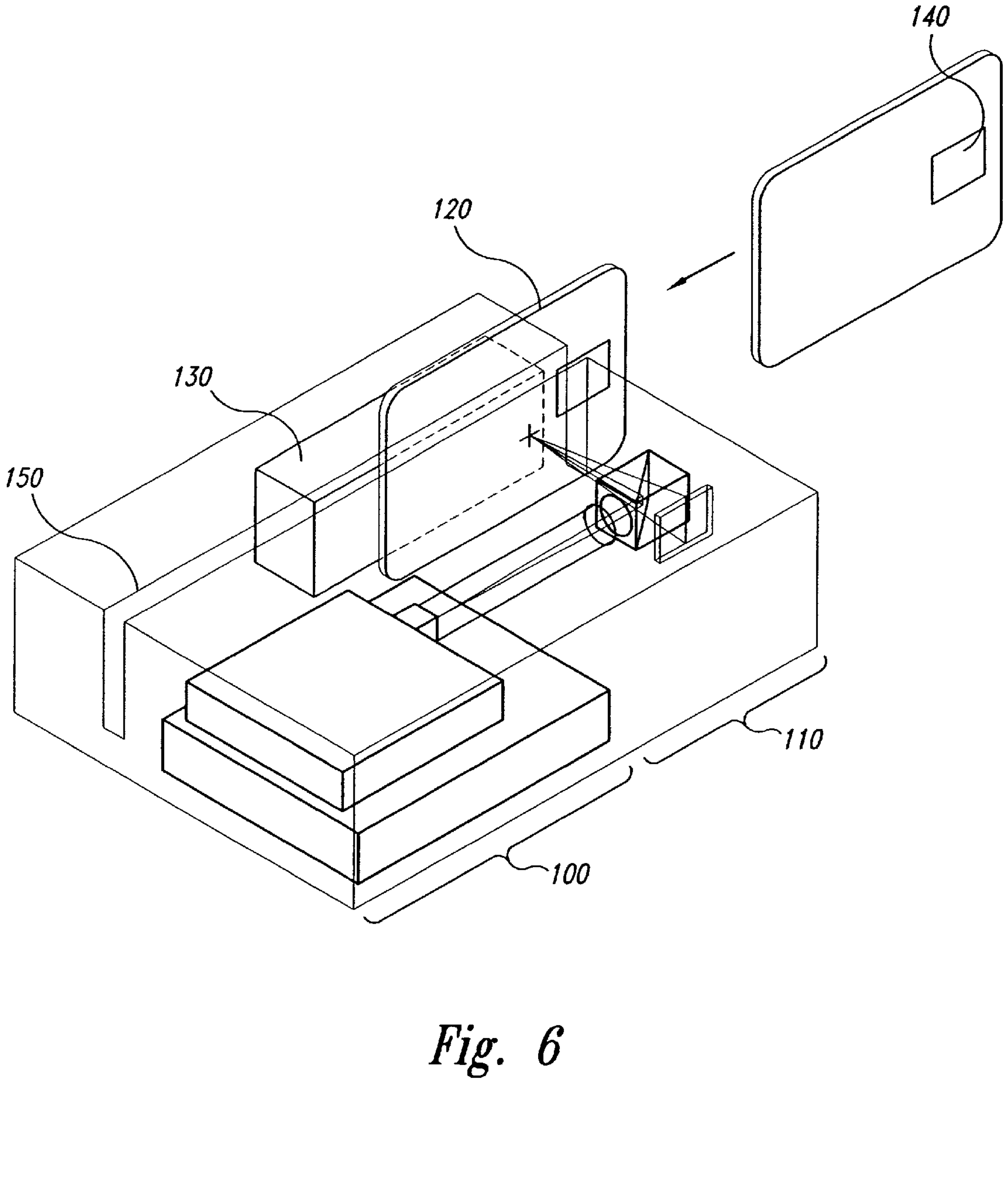


Fig. 6

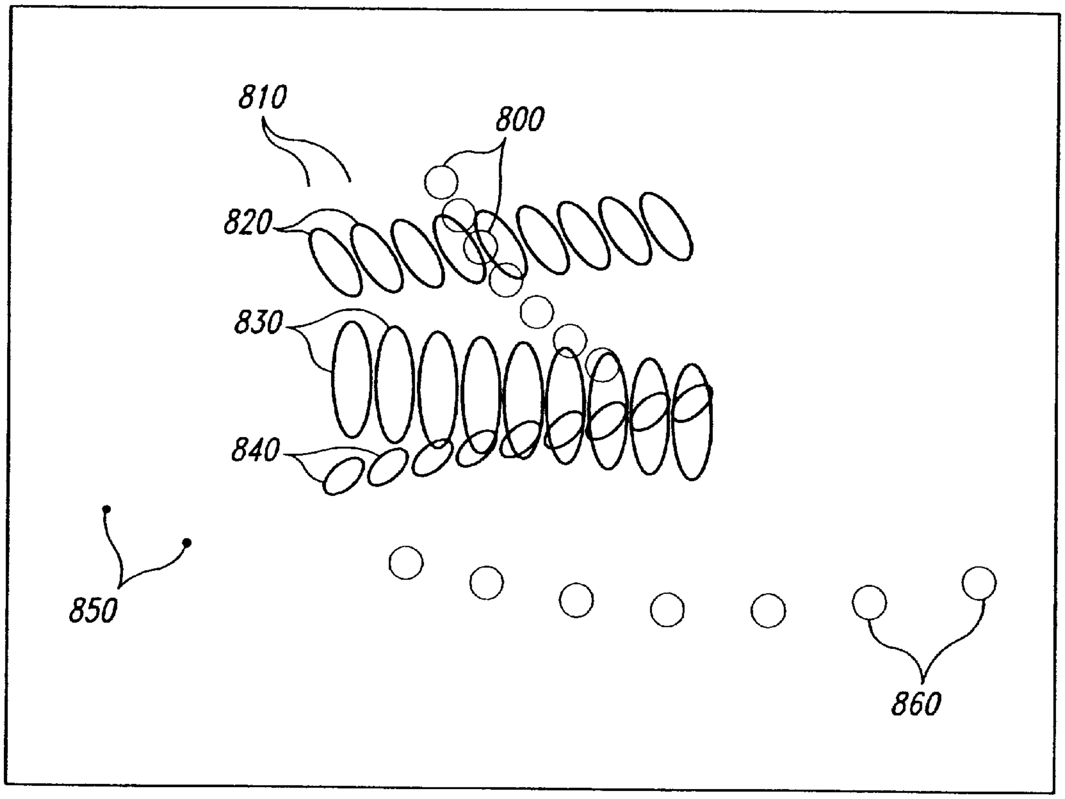


Fig. 7

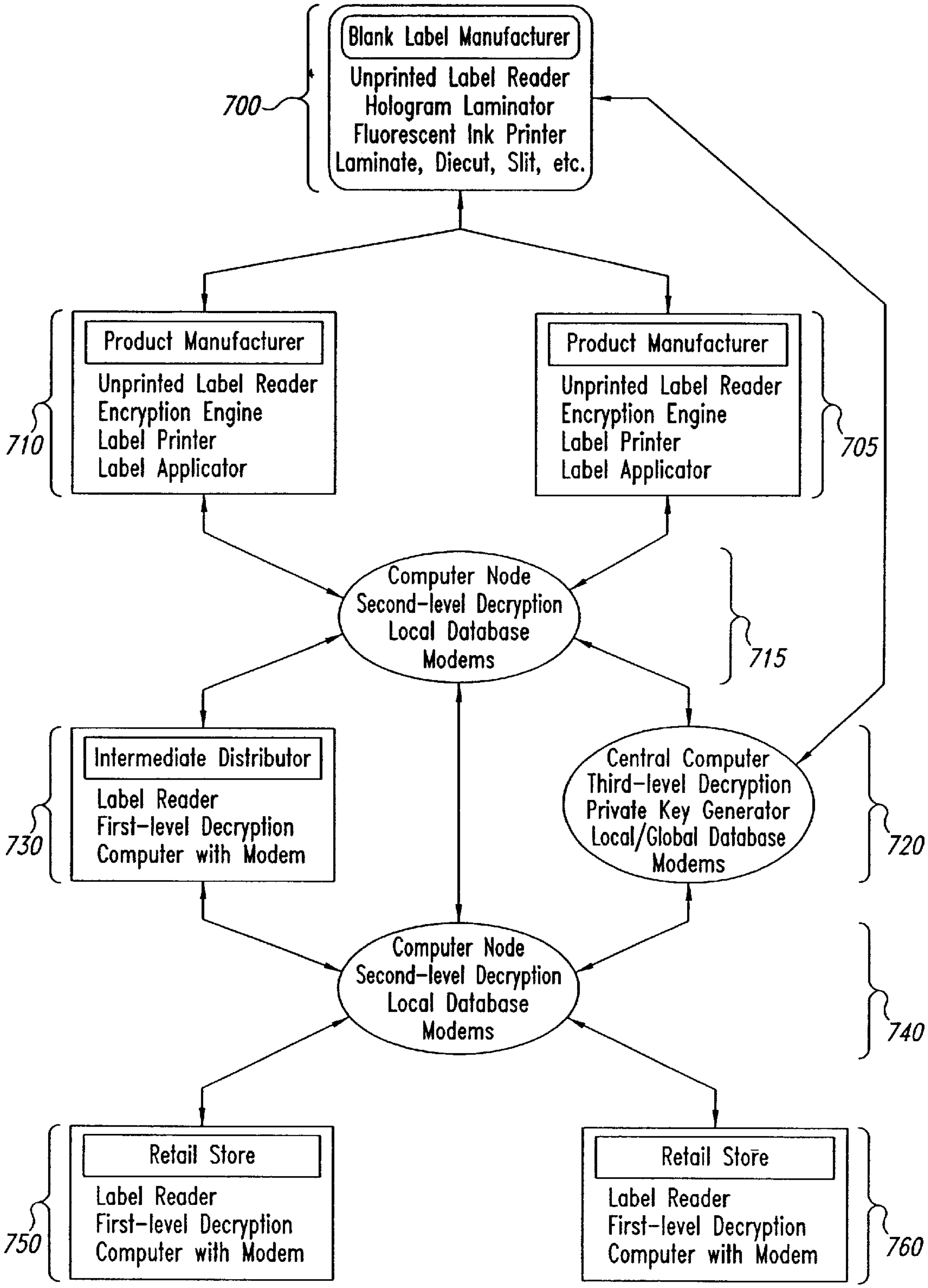

700
Blank Label Manufacturer
Unprinted Label Reader
Hologram Laminator
Fluorescent Ink Printer
Laminate, Diecut, Slit, etc.
710
Product Manufacturer
Unprinted Label Reader
Encryption Engine
Label Printer
Label Applicator
705
Product Manufacturer
Unprinted Label Reader
Encryption Engine
Label Printer
Label Applicator
Computer Node
Second-level Decryption
Local Database
Modems
715
730
Intermediate Distributor
Label Reader
First-level Decryption
Computer with Modem
Central Computer
Third-level Decryption
Private Key Generator
Local/Global Database
Modems
720
Computer Node
Second-level Decryption
Local Database
Modems
740
750
Retail Store
Label Reader
First-level Decryption
Computer with Modem
Retail Store
Label Reader
First-level Decryption
Computer with Modem
760

Fig. 8

METHOD AND APPARATUS FOR READING AND VERIFYING HOLOGRAMS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of pending U.S. patent application Ser. No. 09/881,409, filed Jun. 13, 2001 now U.S. Pat. No. 6,535,638, which is a continuation of U.S. patent application Ser. No. 09/224,260, filed Dec. 31, 1998 now U.S. Pat. No. 6,263,104.

TECHNICAL FIELD

This invention relates to holography, and, more particularly, to a hologram reader/verifier.

BACKGROUND OF THE INVENTION

Prior art hologram readers have depended on the use of holograms having a special format or special characteristics. Examples of prior art hologram readers are illustrated in FIGS. **1***a* and **1***b*. In the hologram reader of FIG. **1***a*, a holographic bar code is illuminated by a laser beam **520** that is generated by a laser **525**. A pattern of spots **505** is then reconstructed onto a set of photodetectors **500** positioned specifically to detect spots at particular positions.

In the hologram reader of FIG. **1***b*, a hologram **510** containing a non-focused image recording is illuminated by a laser beam **520** that is generated by a laser **525**. The laser beam **520** is incident at its reference (or conjugate reference) angle to reconstruct an image **555** onto a ground glass screen **550**, where it can be seen by a human observer **560**.

Another type of prior art hologram reader (not shown) does not actually read a hologram but instead compares a wavefront recorded in a hologram to a reference wavefront. Yet another type of prior art hologram reader (not shown) simply compares a single 2-D view of the hologram to a stored 2-D reference image.

U.S. Pat. No. 4,641,017 to Lopata, entitled Fraud Resistant Credit Card System

U.S. Pat. No. 5,331,443 to Stanisci, entitled Laser Engraved Verification Hologram And Associated Methods

U.S. Pat. No. 4,761,543 to Hayden et al., entitled, Holographic Security Devices And Systems

U.S. Pat. No. 4,108,367 to Hannan, entitled Token And Reader For Vending Machines

U.S. Pat. No. 5,712,731 to Drinkwater et al., entitled Security Device For Security Documents Such As Bank Notes And Credit Cards

U.S. Pat. No. 5,306,899 to Marom, et al. entitled Authentication System For An Item Having A Holographic Display Using A Holographic Record

U.S. Pat. No. 4,131,337 to Moraw, et al., entitled Comparison Reader For Holographic Identification Cards

U.S. Pat. No. 3,905,019 to Aoki, et al., entitled Pattern Recognizing Optical Apparatus

U.S. Pat. No. 5,666,417 to Liang, et al., entitled Fluorescence Authentication Reader With Coaxial Optics

U.S. Pat. No. 5,465,243 to Boardman, et al., entitled Optical Recorder And Reader Of Data On Light Sensitive Media

U.S. Pat. No. RE 035,117 to Rando, et al., entitled Scanner With Coupon Validation

The prior art hologram readers described above and in the above-listed patents are capable of reading holograms only if the holograms are specially adapted for the reader. There is therefore a need for a hologram reader that is capable of reading all kinds of holograms without the need for the holograms to be specially adapted for the reader and is capable of reading variable information from holograms.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1***a* is a schematic drawing showing a prior art hologram reader.

FIG. **1***b* is a schematic drawing showing another prior art hologram reader.

FIG. **2***a* is a schematic drawing of a diffraction pattern typical of a rainbow hologram illuminated at a point using a perpendicular beam.

FIG. **2***b* is a schematic drawing of a diffraction pattern typical of a complex hologram containing both diffraction grating components and rainbow hologram components.

FIG. **3** is a schematic drawing of one embodiment of a hologram reader in accordance with the present invention.

FIG. **4** is a schematic illustration of a typical fluorescent quantum dot including a core and a cap of organic molecules.

FIG. **5** is a schematic drawing of two representative labels containing a hologram, a fluorescent material, and encrypted data in the form of a character string printed directly onto the labels.

FIG. **6** is a schematic illustration of a credit card verifier, including the hologram reader of FIG. **3**, a magnetic stripe reader, and an electronics subsystem.

FIG. **7** is a schematic drawing of the type of pattern formed when half of the diffraction pattern from a single point complex hologram is recorded in an image, half of the diffraction pattern from the next single point along a line in the hologram is recorded slightly offset from the first on the same medium, and so on for a series of points along a line across the hologram.

FIG. **8** is a flow chart of a system for using hologram readers and label printers to detect and track counterfeit products.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **2***a* illustrates the diffraction pattern typically obtained from a reflective “rainbow” hologram **300** when an illumination beam (not shown) is incident perpendicular to the surface of the hologram **300**. The illumination beam incident at an angle corresponding to a reference beam (not shown) angle used to make the hologram **300** will produce a first-order diffracted beam that forms a straight line segment instead of an arc. Inside a first-order arc as shown in FIG. **2***a* are “blobs” **310** of light that relate to the features of the image that would be visible through an illuminated point on the hologram **300**. In order to read a rainbow hologram, it is only necessary to identify and track these blobs **310** as the point of illumination is moved to all salient points on the hologram **300**. For example, the salient points on a hologram can be defined as those points on a line through the hologram **300**, parallel to an edge of a card or label the hologram is on, and a predetermined distance from the edge.

FIG. **2***b* illustrates a diffraction pattern **320** obtained from a combined rainbow hologram and diffraction grating image. Small spots **350**. **360**, **370** formed on the pattern correspond to regions containing diffraction gratings, while lines or arcs **315** correspond to regions containing rainbow hologram components or "2D" hologram components. If the lines or arcs **315** contain blobs **310**, the corresponding hologram component is usually a 3D hologram. If the lines or arcs **315** contain only a substantially featureless or uniform distribution of light, the corresponding hologram component is a "2D" hologram.

While standard image processing techniques can be used to identify the size, shape and location of each blob **310**, it is helpful to take advantage of properties specific to holograms in order to simplify the feature detection and identification task. Unless holograms are blazed, they produce diffraction patterns that are approximately radially symmetric, as are the spots **360** shown in FIG. **2***b*. However, if the holograms are blazed, the positions of the +1 and −1 orders are symmetrical but the brightness of one is substantially higher than that of the other, as are the spots **370** shown in FIG. **2***b*.

For a hologram reader to be able to distinguish between different holograms, certain features of the holograms are important. These features include spot location, blob location, blob asymmetry, blob size, blob shape, blob velocity, blob envelope, and stray light, each of which are discussed below.

The location of a blob can usually be defined as the location of its brightness peak. Alternatively, blob location can be defined as center of mass of the intensity distribution. Radial coordinates are appropriate, since the overall pattern will have a large degree of radial symmetry.

Blob asymmetry can be defined as the ratio of intensities of corresponding blobs in the +1 and −1 orders. Each blob pair will have its own asymmetry.

Blob size can be defined as the maximum width of the region covered by a blob. Coverage in turn can be defined as having an intensity greater than some threshold level determined by the peak intensity of the blob and the background brightness.

In most diffraction patterns from holograms used commercially today, blobs are either point-like or line-like. Line-like blobs occur on the arcs shown in FIG. **2**, while point-like blobs occur anywhere in the diffraction pattern. The hologram diffraction pattern shown in FIG. **2***b* has both kinds of blobs. Other blob shapes are possible, and the image processing software should have the capability of detecting the presence of unusual shapes.

As a hologram is being read by a point of illumination moving across the hologram, the blobs in the diffraction pattern move and change in a piecewise continuous fashion. Blob velocity is the rate-of-change of the blob's location, asymmetry, size and shape in the diffraction pattern with respect to change of location of the illuminated point on the hologram.

In a rainbow hologram, the arc (as seen in FIGS. **2***a* and **2***b*) is defined by the limits of the blob boundaries as they move in response to changing location of the illuminated point. The blobs never move outside the boundaries of the arc. The arc itself corresponds to the size and shape of an H-1 hologram used to make the rainbow hologram, or of an aperture through which H-1 light was transmitted on its way to forming an H-2 hologram. The position, curvature and orientation of the arc, then, provide information about the physical apparatus used to make the hologram.

In most holograms, there is stray light in the diffraction pattern. This light forms dim symmetric patterns upon illumination with a normal-incidence beam, but it has no apparent connection with the visible image. Ordinarily these stray diffraction components result from scattered light in the hologram recording apparatus in which the scattered light is recorded as a hologram along with the object light. A common technique of holographers is to illuminate a hologram with laser light and look through it to see an image of the apparatus that was used to record the hologram.

All information recorded in a hologram is extractable via the diffraction pattern produced (e.g., FIGS. **2***a* and **2***b*) by the illumination of each point of the hologram. Ordinarily, holograms used in document security are mass-produced from a single original master hologram, and the diffraction patterns are the same for all of the holograms. However, new low-cost hologram recording materials and inexpensive lasers have been developed that have begun to make it practical to produce large numbers of one-off holograms, each containing unique information. In order to read the information in such holograms, it is either necessary to design the holograms to be easy to read (as in the prior art), or to design a reader, such as a reader according to a preferred embodiment of the present invention, that is capable of reading all diffraction patterns produced by points of the hologram.

FIG. **3** illustrates a hologram reader in accordance with one embodiment of the present invention. The hologram reader includes a laser diode **600**, focusing optics **630**, preferably with aberration correction, a first beamsplitter **605**, a color-selective filter **662**, an image sensor **620**, a time-gated line array sensor **625**, spectrum-forming optics **615**, **635**, and a second beamsplitter **605**. The laser diode **600**, preferably having the shortest wavelength available, generates a beam **650** that is shaped by the focusing optics **630** to form a converging spherical wave. The converging spherical wave converges to a small spot on a hologram **690**, which is hot-stamped onto a credit card **680**. A suitable laser diode **600** that may be used as the light source for the hologram reader is a green frequency-doubled laser diode. However, blue laser diodes or UV laser diodes may be preferred as they become commercially available at reasonable cost.

The hologram **690** on the card **680** may be transparent, in which case a relief surface of the hologram **690** is preferably coated with a high-refractive index material (not shown) so that the hologram **690** is significantly bright. Suitable high-refractive index materials include titanium oxide or zinc sulfide. If the hologram **690** is transparent, the surface of the card **680** underneath the hologram **690** may be provided with features detectable through the hologram, such as patterns of fluorescent ink, colored ink, fibers, magnetic inks, or optically variable inks.

In operation, the laser beam **650** diffracts from the hologram **690** to form a pattern on the image sensor **620**. The image sensor **620** does not sense the entire image in the hologram. Instead, the image sensor **620** senses the pattern of diffracted light from one illuminated spot on the hologram **690**. The color-selective filter **662** ensures that the image sensor **620** receives only light of the same color as the illuminating laser beam **650**, and therefore receives predominantly diffracted, scattered and reflected light. If the illuminating laser beam **650** is directed at an appropriate angle to the hologram **690**, corresponding to the angle between reference and object beams (not shown) used in manufacturing the hologram **690**, only positive diffracted orders will fall onto the image sensor **620** placed directly above the hologram. Alternatively, the illuminating laser beam **650** may be directed perpendicularly to the hologram **690**, as indicated in FIG. **3**, thereby enabling the image sensor **620** to receive both positive and negative diffracted orders while placed directly above the hologram **690**.

Illumination of fluorescent inks printed on the substrate of the card **680** induces the emission of fluorescent light. This fluorescent light passes through the spectrum-forming optics **615**, **635** to the second beamsplitter **605**, which directs the fluorescent light onto the time-gated line array sensor **625**. The time-gated line array sensor **625** images the spectrum of the fluorescent light. A stop **692** blocks the direct reflection (zero-order diffracted beam) of the illumination laser beam **650** from striking the line array sensor **625**.

Fluorescence from different substances has two primary distinguishing features: emission spectrum and temporal behavior. For example, many organic dyes have a very short fluorescence lifetime so that if they are illuminated with a picosecond pulse of excitation light, they emit a brief pulse of fluorescence shorter than a nanosecond. Other fluorescent substances emit fluorescence for hundreds of nanoseconds following excitation. Many materials are fluorescent to some degree, but most have short fluorescence lifetimes; so it is advantageous to use a fluorescent ink with a long fluorescence lifetime, thereby providing the opportunity to exclude background fluorescence by time-gating methods.

In the embodiment illustrated in FIG. **3**, the line array sensor **625** is time-gated and the laser diode **600** is pulsed. If the fluorescence lifetime of the fluorophores in the printing on the substrate of the card **680** is longer than typical fluorescence lifetimes of ordinary materials, then by selectively detecting only fluorescent light received more than, say, 100 nanoseconds following the excitation pulse, background fluorescence is effectively excluded.

One example of a suitable fluorescent material is formed using quantum dots **210**, as illustrated in FIG. **4**. The quantum dots **210** are preferably composed of CdSe and coated with a cap **220** of ZnSe. Such ZnSe-capped CdSe quantum dots are known to have fluorescence lifetimes on the order of 100 nanoseconds. Alternatively, the line array sensor **625** can simply have a response time on the order of tens or hundreds of nanoseconds, and the laser diode **600** can be modulated at a rate of one to tens of megahertz. The fluorescence lifetime can then be measured as a function of the phase difference between the illumination modulation and the fluorescence signal. In any case, the line array sensor **625** detects the fluorescence spectrum of any ink or other fluorescing substance under the hologram **690** at the illuminated spot.

Examples of labels **400**, **410** formed by holograms **450** having an underlying fluorescent material **430** are illustrated in FIG. **5**. In both cases, the hologram **450** is semi-transparent hot stamping foil applied over a substrate **460**, which may be formed by paper. The fluorescent material **430** is preferably printed directly on the substrate **460**. The hologram **450** has a void in which encrypted data in the form of a character string **470** is printed directly onto the substrate **460**. The labels **400**, **410** preferably have an adhesive backing (not shown) and a peel-off protective silicone paper back (not shown).

The fluorescent substance **430** may be a fluorescent ink containing fluorophores. It is advantageous to use a patterned fluorescent substance **430** on the substrate **460** having a distinctive fluorescence spectrum. A suitable fluorescent substance **430** is a fluorescent ink containing fluorophores, such as the ZnS-capped CdSe quantum dots **420** described above. The quantum dots **420** are preferably of specific sizes so that the fluorescence spectra will be relatively narrow. Specific organic dyes such as Rhodamine 6G, which has a distinctive peak fluorescence wavelength, may be used. The fluorescent substance **430** is described in greater detail in co-pending patent application entitled QUANTUM DOT SECURITY DEVICE AND METHOD, filed concurrently herewith, and which is incorporated herein by reference.

The credit card **120** of FIG. **5** is representative of the full class of labels, tags, documents, identification cards, authentication labels, paper currencies, seals, and other items on which a hologram, diffractive image, security label or other security device may be placed. The holograms **690**, **450**. **140** shown in FIGS. **3**, **5** and **6**, respectively, are representative of the full class of diffractive images including dot-matrix holograms, 2D3D holograms, stereograms, kinegrams, kineforms, Bragg holograms, embossed holograms, holograms embossed into colored film, holographic hot stamping foils, pixelgrams, electron-beam diffractive patterns, and binary optical patterns. As used herein, the term "substrate" means any surface or substance on which a hologram is placed or held in close proximity to, including any inks, fibers, embossing, chemical treating, magnetic properties, or other properties or features of the surface or substance.

Returning to FIG. **3**, the image sensor **620**, in addition to sensing the pattern of light diffracted by the hologram **690** or **450**, also detects light scattered from the substrate of the card **680** or **460** due to fibers, texture, or other properties of the substrate, material. Light diffracted by a hologram **690**, **450** typically produces a much higher contrast pattern than light scattered uniformly by, for example, a white substrate. Holograms, however, typically produce distinctive diffraction patterns that can be subtracted from the sensed pattern. Changes in the average intensity of light received by the image sensor **620**, with the diffracted patterns subtracted out, correspond to changes in the amount of diffusely scattered light from the substrate due to printed patterns or other light-affecting patterns on the substrate. Thus, the hologram reader shown in FIG. **3** can read holograms, fluorescent patterns, and light scattering or light absorbing patterns, as long as such patterns are evident in light of the wavelength range emitted by the laser diode **600**. Although a laser diode **600** is used as the illumination source for the hologram reader of FIG. **3**, it will be understood that other light sources may be used, such as any well-collimated (spatially coherent) white light source. In such cases, the diffractive patterns, spots and scattered light will usually be discernible by the image sensor **620**.

Components, modules and combinations of components in the optical and electronic subsystems of the reader may be substituted for other equivalent components, modules, and combinations of components may be substituted, with the objectives of sensing the diffracted light pattern from the illuminated spot on the hologram and/or the amount of scattered light from each point on or under the hologram, and/or the amount, timing or spectrum of fluorescence emitted from the hologram or its substrate.

Wavelength-selective filters (not shown) may be inserted in the optical path from the hologram **690** to the image sensor **620** and/or in the optical path from the hologram **690** to the time-gated line array sensor **625**. The wavelength-selective filters limit detected light to a desired range of wavelengths. For example, since scattered light and diffracted light are of the same wavelength as the laser diode **650**, a filter that is transmissive to the wavelength of the laser diode **650** but reflective or absorptive to other wavelengths may be advantageously inserted between the sensor **620** and beamsplitter **610**. Similarly, a filter that is reflective or absorptive to light at the wavelength of the laser diode **650** and transmissive to light in the fluorescence bandwidth of the fluorophores may be inserted between the sensor **625** and beamsplitter **605**.

Alternatively, the beamsplitter **610** may be a polarizing beamsplitter and a quarter-wave plate **608** may be inserted between the beamsplitter **610** and the hologram **690** such that laser light is transmitted nearly 100% at the beamsplitter on its way to the hologram **690**, and is also nearly 100% reflected on its way to the image sensor **620**. In this case, the beamsplitter **610** may be a wavelength-selective polarizing beamsplitter so that most of the fluorescence light is directed to the line array detector **625**, as indicated in FIG. **6**.

The hologram reader shown in FIG. **3** may be combined with readers using other technologies. For example, a reader/verifier using multiple technologies is shown in FIG. **6** for use in detecting counterfeit credit cards. In addition to including an optical read head **110**, which may be the hologram reader of FIG. **3**, the reader/verifier of FIG. **6** includes a conventional magnetic stripe reader **130**. The optical read head **110** reads a hologram **140** on a credit card **120**, while the magnetic stripe reader **130** reads information recorded on a conventional magnetic stripe (not shown) on the credit card **120** while the credit card **120** slides through a slot **150**. The reader/verifier also includes an electronics subsystem **100**. The electronics subsystem **100** preferably includes a microprocessor (not shown), a field programmable gate array ("FPGA") (not shown) and a read only memory ("ROM") (not shown), which contains software that is executed by the microprocessor. The electronics subsystem **100** also preferably includes means for communicating with external systems such as a computer (not shown) or telephone network (not shown).

The FPGA in the electronics subsystem **100** is provided to do the image processing. An alternative implementation uses an Artificial Neural Network (ANN). In fact, any image processing means capable of recognizing salient features of a diffraction pattern may be used to distinguish between the diffraction patterns of different holograms and of counterfeit and valid holograms or other diffractive anti-counterfeiting devices known variously as DOVIDs, holograms, stereograms, kineforms, dot-matrix holograms, kinegrams, pixelgrams and so on.

A suitable FPGA that can be used in the electronics subsystem is a model 6216 FPGA available from Xilinx. The FPGA can be programmed to perform almost any desired signal-processing function. For example, the FPGA may be programmed by downloading a configuration file to the FPGA. The configuration file determines the pattern of interconnections among the logic gates on the FPGA. In the case of the Xilinx **6216** FPGA, the FPGA has 128 pins available for input and output, and there are approximately 35,000 logic gates on the FPGA. All of the logic gates can be operated in parallel, synchronously or asynchronously. There are also design tools commercially available for designing the configuration file for the FPGA. A preferred approach in some applications, however, employs evolutionary computation methods to design configuration files. This evolutionary computing approach is within the skills of an individual or team of individuals having ordinary skill in genetic algorithms or genetic programming, FPGA structure and design methods, chip-level electronics and the mathematics of image processing. Alternatively, evolutionary design tools for FPGA configuration files are commercially available from New Light Industries, Ltd., of Spokane, Wash. 99224 under the trade name of "FPGA-Generator"™.

In the preferred embodiment of the invention, an evolutionary technique is used to design FPGA-based algorithms in the electronics subsystem for feature recognition and extraction. In one version, the following steps are carried out:

1. A target function is defined by visually identifying features in a set of diffraction patterns to produce feature-tagged images.
2. A trial function is defined by specifying a matrix to serve as a convolution template.
3. A population of templates is generated randomly, and each member of the population is used to produce a set of convolved images of a training set of images
4. The convolved images produced by each member of the population are compared to the target set of feature-tagged images to produce a fitness value for the member, such that the fitness represents the degree of correspondence between the produced convolved images and the feature-tagged images.
5. Using standard genetic algorithm techniques, the templates are recombined and/or mutated depending on their fitness to evolve an optimum template.

The precise choice of recombination and mutation operators, and the other GA parameters such as recombination rate, mutation rate and size, population size, elitism, etc., can affect the speed at which evolution proceeds. At this time, there is not a known best choice of operators and GA parameters for all classes of problems.

In operation, the reader/verifier of FIG. **6** detects counterfeit credit cards **120** by reading the hologram **140**. More specifically, a series of points across the hologram **140** are illuminated as explained above with reference to FIG. **3** as the credit card **120** is drawn through the slot **150**. Diffraction patterns from the points are formed on the image sensor **620** where they are converted to video signals. The video signals are analyzed by the electronics subsystem **100** to extract a feature vector corresponding to the values of the significant features of the diffraction patterns in the hologram **140**. The feature vector is then compared to a database of feature vectors from valid and invalid holograms, and the hologram **140** is classified according to the similarity of its feature vector to vectors in the database. Data identifying the feature vectors for a valid hologram may also possibly be stored on the magnetic stripe and read by the magnetic stripe reader **130** for comparison with the feature vectors for the hologram **140**.

The electronics subsystem **100** may also build a representation of the scattering and fluorescence information extracted from the credit card **120** to determine validity or invalidity of the credit card **120**. The optical read head **110** used in the hologram reader of FIG. **6** is thus capable of sensing diffractive properties, fluorescence properties, light scattering properties and light absorptive properties at a point on the credit card **120**. If the imaging sensor and/or the line array sensor or the associated electronics are appropriately designed, the reader/verifier can also sense differences between those properties from point-to-point.

A preferred way to build a representation of the diffraction information in the hologram **140** is to detect intensity peaks in the diffraction pattern and generate a list of the locations, sharpness and relative brightness of the peaks. When a series of diffraction patterns are observed at a series of regions across the item, it is advantageous to represent the diffractive properties of the entire item either as a list-of-lists or as a compiled, sorted list.

A simple way to represent the diffraction information is to halve the diffraction pattern and save only the position and intensity data obtained from that portion. A representative image of a complete set of diffraction patterns from a line across a hologram is then constructed by stacking the data, as illustrated in FIG. **7**. A plurality of blobs **820**, **830**, **840** then trace paths across the resulting composite image, and any spots **800**, **850**, **860** from diffraction grating components also trace paths across the resulting composite image. This representative image may then be tested by convolving it with a similarly obtained representative image of each of one or more reference images, which may correspond for example to valid and counterfeit holograms. The paths due to blob and spot motion obtained as in FIG. **7** are substantially invariant with respect to the particular choice of hologram points that are sampled, as long as the scale is essentially unchanged.

As mentioned above, an advantage of the hologram reader illustrated in FIG. **3** is that it can read virtually any type of hologram. Thus a variety of techniques can be used to record holograms that are usable with the hologram reader of FIG. **3**. Each of these hologram has its own particular set of characteristics. Some of the characteristics or parameters useful for classifying different kinds of holograms and diffractive images include:

1. recording medium;
2. reference and object beam angles and positions;
3. dot size, shape, spacing, placement, grating angle, and grating period in dot-matrix holograms;
4. rainbow (Benton), classical, 2D3D, stereogram, or dot matrix holograms;
5. transmissive or reflective;
6. reflectivity-enhancing layers;
7. color selectivity of recording medium and Bragg grating structure;
8. color properties of the recording and reconstruction geometry;
9. encoded reference beam or object beam; and
10. features and characteristics of a substrate on which the hologram is laminated or hot-stamped.

The hologram reader of FIG. **3** may be integrated into a comprehensive anticounterfeit/security system, as illustrated in FIG. **8**. The anticounterfeit/security includes one or more sites **700** for manufacturing anticounterfeit/security labels bearing detectable random data on substrates covered by transparent holograms, one or more manufacturing sites **710**, **705** for products, one or more hologram readers at each manufacturing site, label printers at each manufacturing site, one or more intermediate distribution points **730**, **720** with hologram readers, one or more distribution endpoints **750**, **760** with hologram readers, and a computer network consisting of a hierarchy of nodes **740**, **750**, **720**.

The random data (e.g., in the labels **400**, **410** shown in FIG. **5**, the locations of fluorescent dots **420** under the holograms **450**) are read at the label manufacturing sites **700** and stored in a database. Each hologram printer at the manufacturing sites **700** has associated with it an encryption engine. The encryption engine combines a representation of the random data corresponding to the dots **420** on the labels **400**, **410** with private key information securely hidden inside the encryption engine and variable information generated inside the encryption engine to produce an encrypted character string **470** (FIG. **5**), which is then printed on the labels **400**, **410** by the label printer.

The printed labels are placed on products, which are distributed via intermediate and final distribution points. The labels may be read at the distribution points by hologram readers that are associated with decryption engines. The hologram readers read the random data from the substrates underneath the holograms and use the random data as a public key to decrypt the character string printed on the label, without determining the private key securely hidden in the encryption engine. If a label has been counterfeited or illegitimately produced, either the character string will not be decryptable or the random data will not be contained in the label manufacturer's database.

The term, "character string" is used here inclusively of any encoded information, including bar codes, optically readable alphanumeric characters, encoded magnetic stripes, magnetically readable alphanumeric characters optically readable bit strings, icons, and the like.

Information relating to the particular labels passing through each distribution point and their validity or invalidity is collected by a network of computer nodes and analyzed at one or more sites. A central computer node may download information to the distribution sites to alert them to particular counterfeiting threats or to upgrade their decryption engines and/or download upgrades to encryption engines to the label printers.

The anticounterfeit/security system illustrated in FIG. **8** is capable of detecting counterfeit products at any point in the manufacturing and distribution flow, and can also collect and analyze product flow. If counterfeits are detected, the temporal and geographic pattern of their appearance can be used to help track down their sources and distribution channels. The system provides the ability to detect factory overruns of labels or products, monitor the number of labels produced, and so on.

It is to be understood that even though various embodiments and advantages of the present invention have been set forth in the foregoing description, the above disclosure is illustrative only, and changes may be made in detail, and yet remain within the broad principles of the invention. For example, many of the components described above may be implemented using either digital or analog circuitry, or a combination of both, and also, where appropriate, may be realized through software executing on suitable processing circuitry. Therefore, the present invention is to be limited only by the appended claims.

What is claimed is:

1. A scanner for extracting information from a security device on a surface, said scanner comprising:

a light source constructed to generate a light beam having a predetermined temporal modulation;

focusing optics to direct the light from the light source to illuminate a spot on the security device;

spectrally dispersive optics to collect light that is at least one of diffracted, scattered and emitted from the spot on the security device and focus the collected light to a spectrum, and

a time-gated sensor to detect a time-dependent distribution of light in the spectrum.

2. The scanner of claim **1** wherein the time-dependent distribution of light in the spectrum is compared to a set of template distributions.

3. The scanner of claim **1**, wherein the time gated sensor detects a series of spectra of light emitted by particles in said security device due to the illumination of a corresponding series of spots on the security device.

4. A security system comprising:

an arrangement of light-emitting particles on a surface, said arrangement forming a pattern of varying spectral emission properties corresponding to each of the light emitting particles applied to an object

a scanner for extracting information from the security device, said scanner comprising:

a light source constructed to generate a light beam having a predetermined temporal modulation;

focusing optics to direct the light from the light source to illuminate a spot on the security device;

spectrally dispersive optics to collect light that is at least one of diffracted, scattered and emitted from the spot on the security device and focus the collected light to a spectrum, and

a time-gated sensor to detect a time-dependent distribution of light in the spectrum; and

a mover that changes a location of said illuminated spot relative to the security device.

5. The system of claim **4**, further comprising a recorder that records the spatially varying spectral emission properties of the security device, and wherein said arrangement of kinds of particles in the security device further comprises a representation of information.

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