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**McGrew**

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

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5,756,981 *	5/1998	Roustaci et al. ....	235/462
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(76) Inventor: **Stephen P. McGrew**, 9715 W. Sunset Hwy., Spokane, WA (US) 99224

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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.

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07302338	11/1995	(JP) .

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(21) Appl. No.: **09/224,260**

(22) Filed: **Dec. 31, 1998**

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(51) **Int. Cl.**<sup>7</sup> ..... **G06K 9/76**

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(52) **U.S. Cl.** ..... **382/210**

(57) **ABSTRACT**

(58) **Field of Search** ..... 382/210, 211, 382/212, 213, 214, 109, 141, 143, 279; 235/462, 472, 459; 356/30

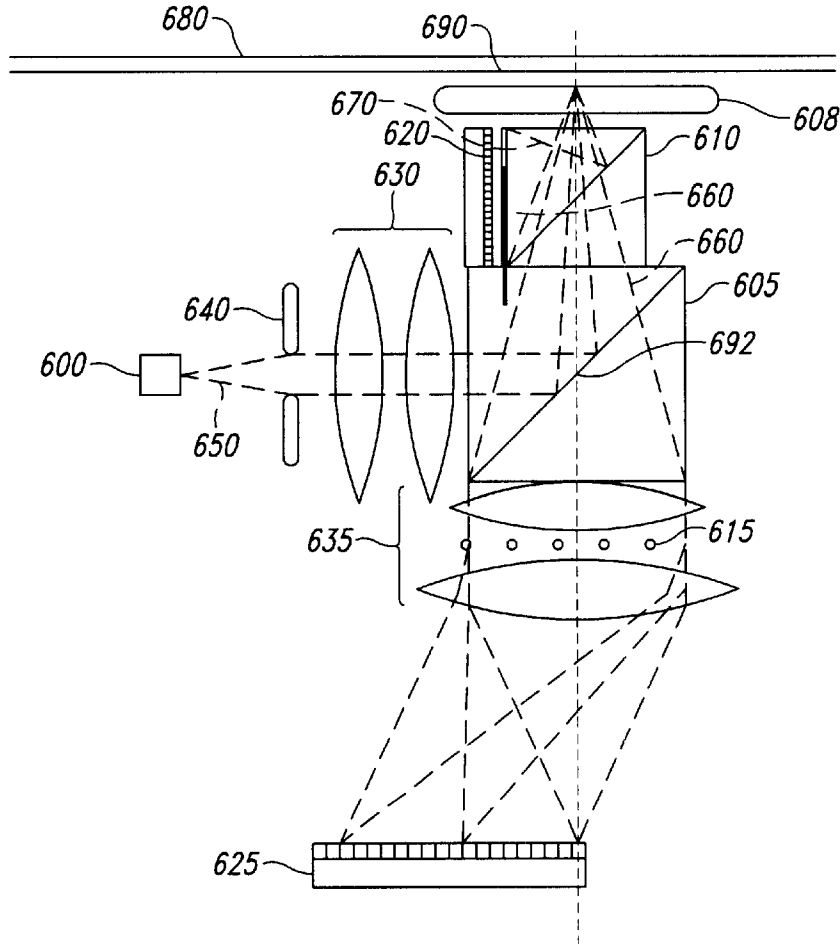
A system and method for reading the information stored in holograms and other diffractive objects. The information is read by analyzing the diffraction pattern produced when a laser beam is focused onto a small spot on the object and scanned across the object.

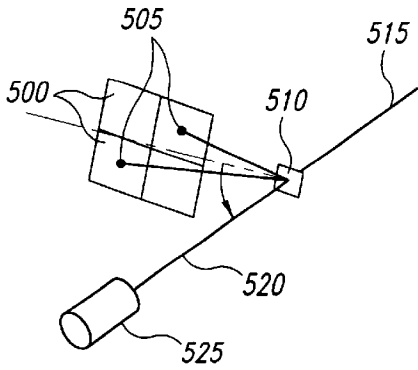
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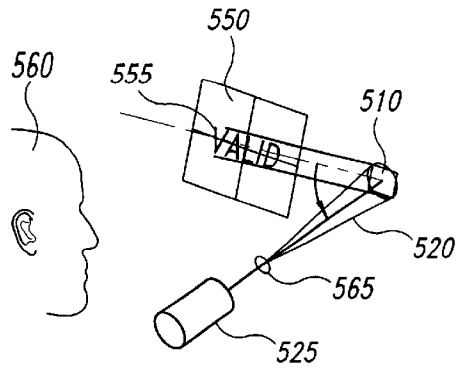
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**10 Claims, 6 Drawing Sheets**

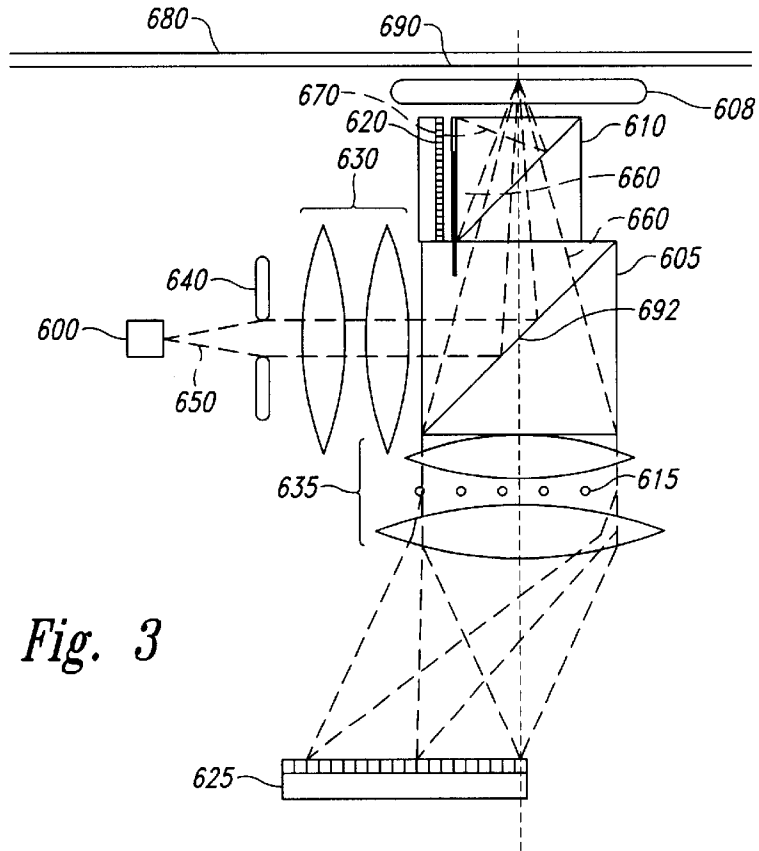




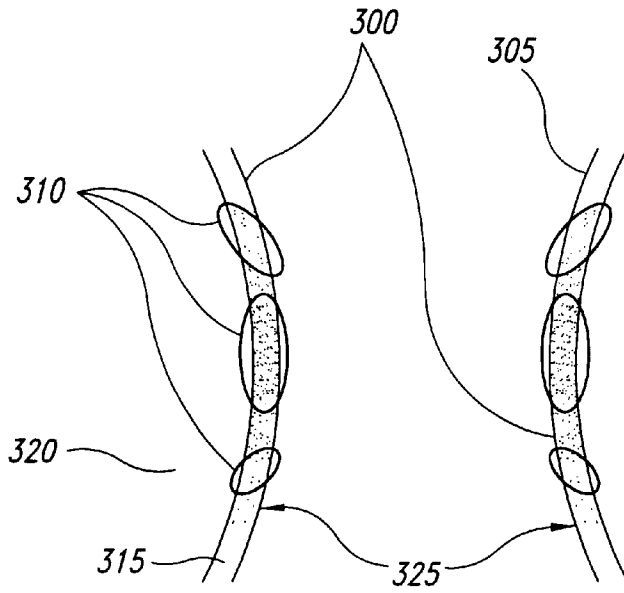
*Fig. 1A*  
*(Prior Art)*



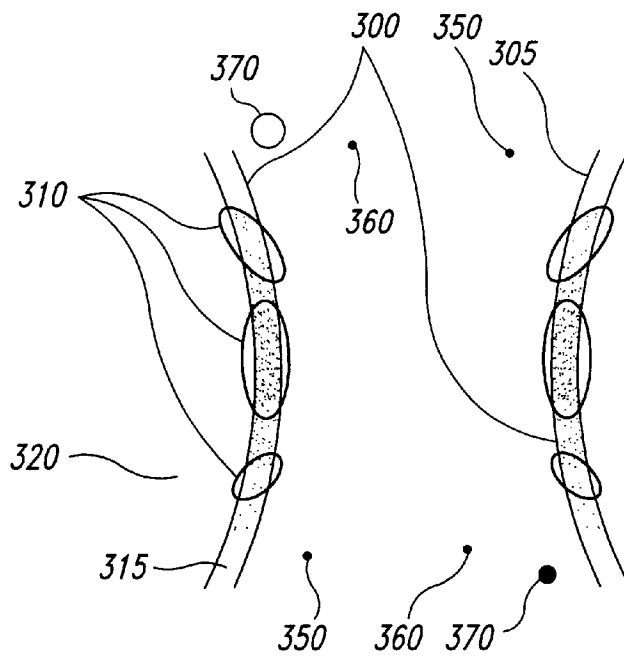
*Fig. 1B*  
*(Prior Art)*



*Fig. 3*



*Fig. 2A*



*Fig. 2B*

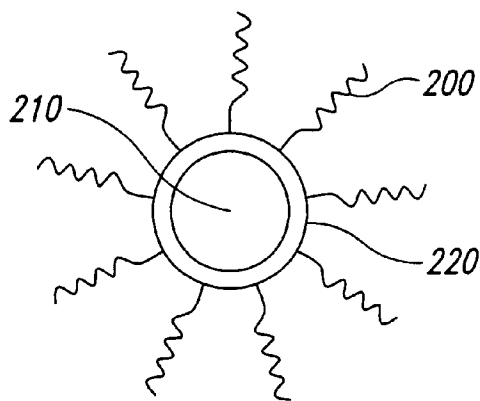


Fig. 4

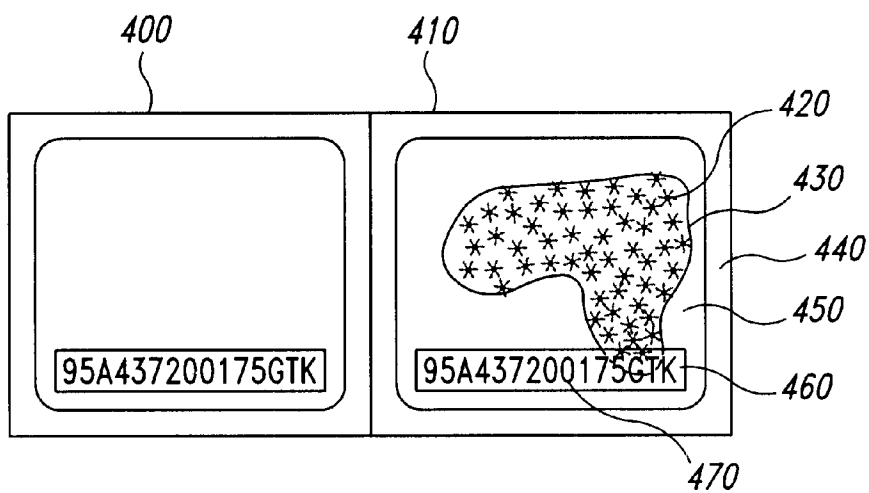


Fig. 5

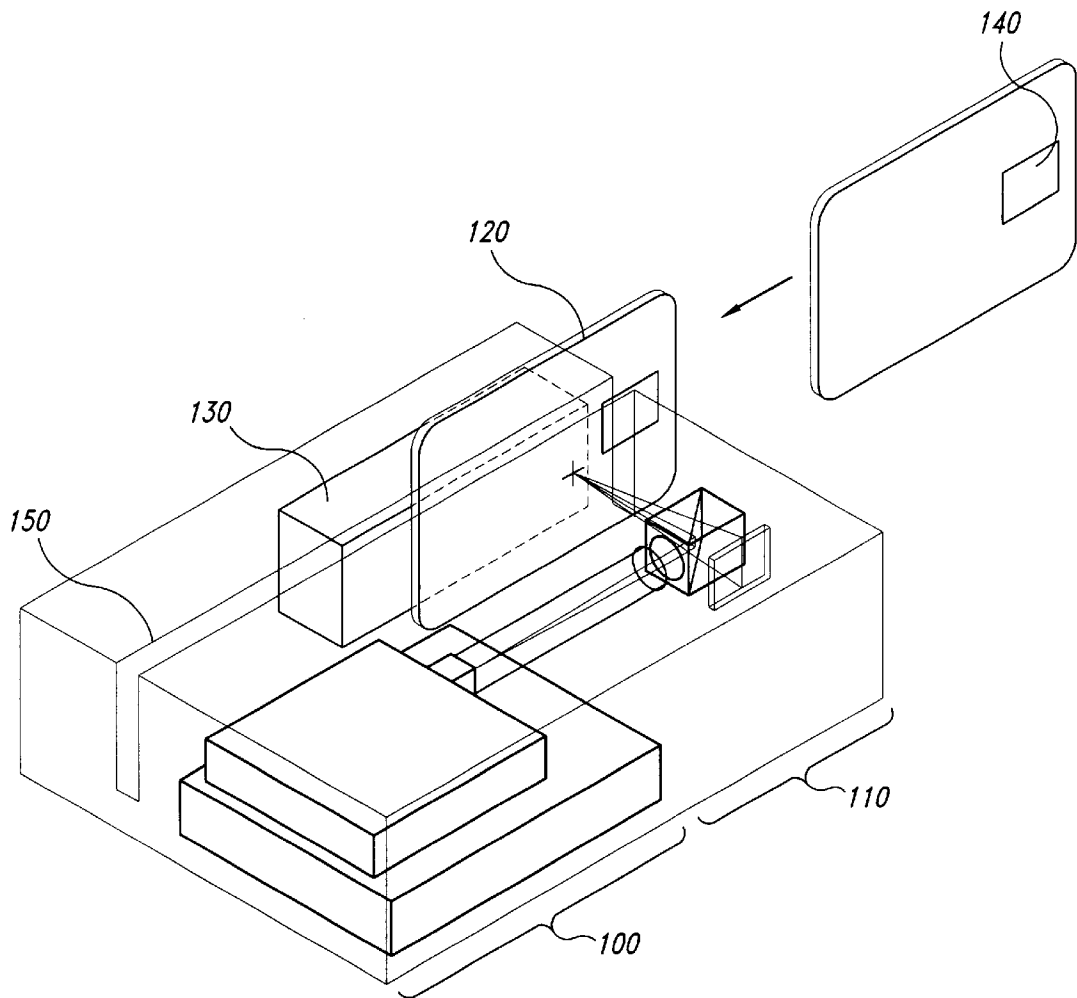
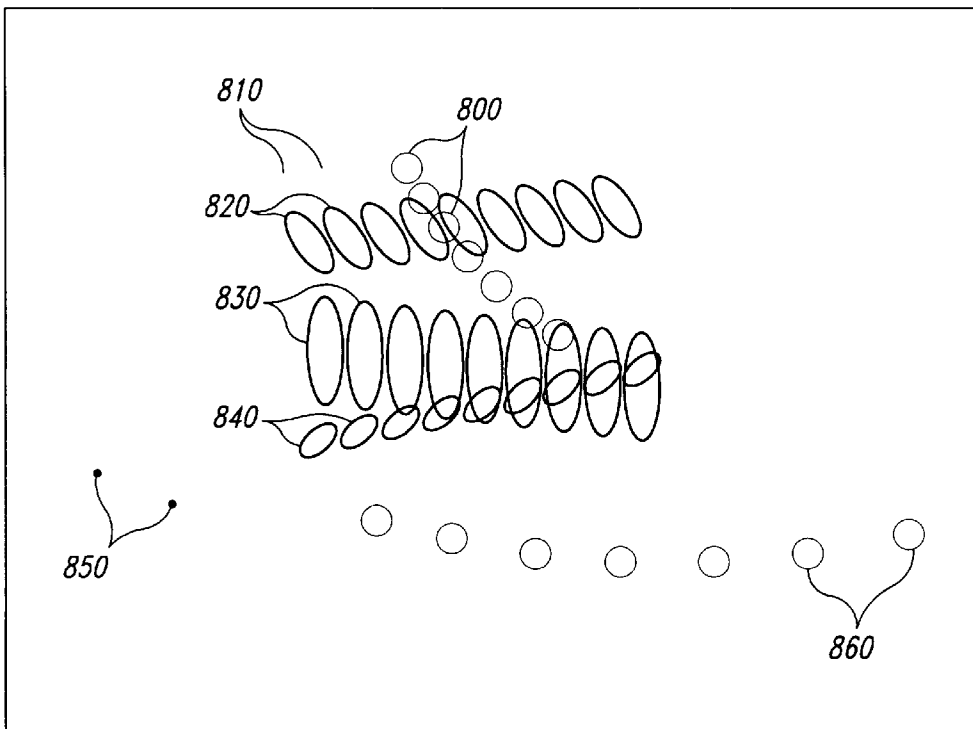


Fig. 6



*Fig. 7*

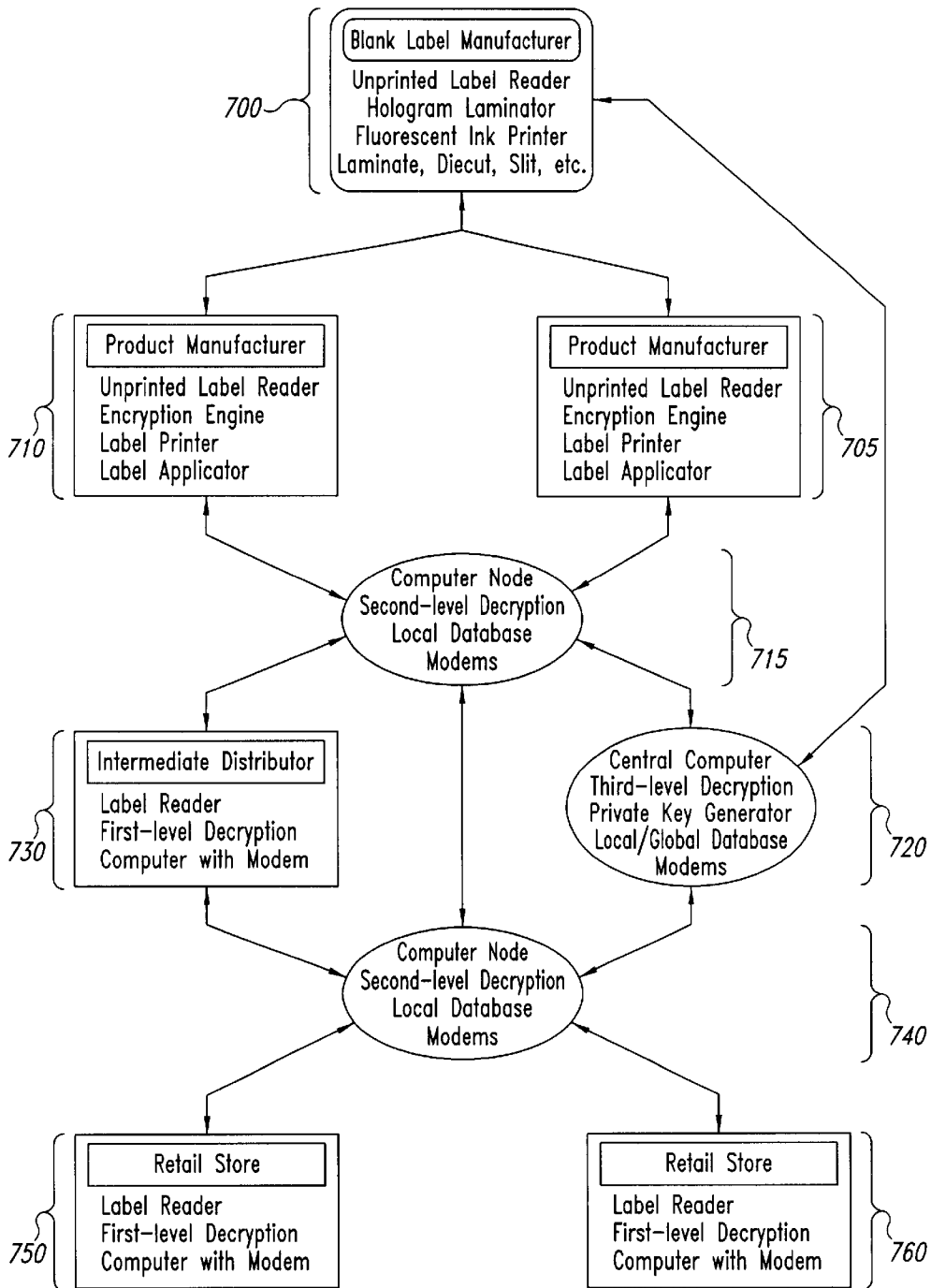


Fig. 8

## METHOD AND APPARATUS FOR READING AND VERIFYING HOLOGRAMS

### CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is related to the inventor's U.S. patent application entitled QUANTUM DOT SECURITY DEVICE AND METHOD, filed Dec. 31, 1998, the disclosure of which is incorporated herein by reference.

### 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. 1a and 1b. In the hologram reader of FIG. 1a, 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. 1b, 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. 1a is a schematic drawing showing a prior art hologram reader.

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

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

FIG. 2b 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 all 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. 2a 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. 2a 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. 2b 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. **2b**. 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. **2b**.

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. **2b** 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. **2a** and **2b**) 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. **2a** and **2b**) 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-nmatrix 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"<sup>TM</sup>.

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. An apparatus for extracting information from diffractive objects comprising:
  - means for illuminating a diffractive object with spatially coherent radiation;
  - means for detecting at least a portion of the pattern of radiation diffracted by the object;
  - means for convolving the detected portion of the pattern with a template pattern to produce a transformed version of the pattern;
  - means for identifying and locating peak values in the transformed version;
  - means for representing as a vector the locations of the peak values in a transformed version of the pattern; and
  - means for comparing the vector to a set of reference vectors in a database to classify the vector and thereby to classify the diffraction pattern from the diffractive object.
2. A method for designing a template for transforming a pattern by convolution, comprising:
  - providing a set of training patterns and corresponding target patterns;
  - providing an initial set of trial templates to serve as the initial population in a genetic algorithm;
  - defining a fitness value as the degree of correspondence between the result of convolving a trial template with a training pattern, and the corresponding target pattern; and
  - using the genetic algorithm with the fitness value and the population to evolve a template which, when convolved with every training pattern, produces a convolved pattern that approximates the target pattern.

11

- 3. A scanner for extracting detailed structural information from a diffractive image, comprising:
  - a laser source constructed to generate a laser beam;
  - focusing optics constructed to direct the laser beam from the laser source to a spot;
  - means for placing a diffractive image such that the spot illuminates a region on the diffractive image;
  - means for detecting a pattern of light diffracted from the region; and
  - means for comparing the pattern of light to a reference pattern.
- 4. The scanner of claim 3, wherein the spot has a diameter of less than 1 mm.
- 5. A scanner for extracting detailed structural information from a diffractive image, comprising:
  - a laser source constructed to generate a laser beam;
  - focusing optics constructed to direct the laser beam from the laser source to a spot;
  - means for placing a diffractive image such that the spot illuminates a region on the diffractive image;
  - means for moving the image relative to the spot such that the spot illuminates a series of regions on the image;
  - means for detecting a respective series of patterns of light diffracted from the series of regions; and
  - means for comparing the series of patterns of light to a reference series of patterns.
- 6. The scanner of claim 5, wherein the spot has a diameter of less than 1 mm.

12

- 7. The scanner of claim 5, wherein the reference series of patterns is represented in the form of a set of parametrized curves.
- 8. The scanner of claim 5, wherein the reference series of patterns is represented in the form of a two-dimensional array of values.
- 9. The scanner of claim 8, wherein the two-dimensional array of values comprise numbers, intensities, vectors, or character strings.
- 10. A method for recognizing patterns in a first series of images comprising:
  - identifying features of individual images in the first series;
  - generating a second series of images in which at least some pixels corresponding to features of the images in the second series are enhanced in brightness and other pixels are reduced in brightness;
  - generating a composite image by combining a sequential portion of at least N images in the second series into a single image, the pixels from the Nth image in the second series being offset according to a function of N with respect to the pixels in the composite image corresponding the first image in the second series; and
  - comparing the composite image with a reference image, the degree of correspondence between the composite image and reference image providing a measure of the resemblance between features depending on correlations between sequences of the first images.

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