

METHOD AND APPARATUS FOR ILLUMINATING FILM FOR AUTOMATED INSPECTION

5 CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 60/890415, filed February 16, 2007, the disclosure of which is incorporated by reference herein in its entirety.

10 TECHNICAL FIELD

The present disclosure is related to machine vision, and more particularly for the illumination of e.g. structured optical films so as to maximize the recognition of anomalies.

15 BACKGROUND

In recent years with the assistance of capable computing, it has been possible to use automated equipment to perform some inspection tasks that previously required a trained human inspector. Such “machine vision” techniques have become more sophisticated, and among other things have been employed for the inspection of webs of indefinite length material.

Proper web illumination techniques are needed for the proper operation of machine vision systems. A particularly demanding example is inspecting for surface defects on structured optical films. One technique that has been employed is the so-called, “diffuse transmitted light” technique. When using the diffuse transmitted lighting technique with structured optical films, a diffuse light source illuminates the structured side of the optical film with light from many different angles relative to the film’s surface. A camera, situated on the non-structured side of the film, is focused on the illuminated area of the film. When certain types of anomalies pass through the illuminated area, the anomalous regions may transmit light differently than non-anomalous regions of the film, and this difference detected by the camera. Certain surface anomalies, such as scratches in the film, may be observed by the camera as being brighter or darker than other areas of the film.

Another technique, the so called “far dark field” technique, is used to detect anomalies that strongly scatter light. When using the far dark field technique, one or two light sources are placed so that their light falls upon the film to be inspected at an angle to the line of vision of the camera. The camera will normally see no light from these sources. Only when certain surface anomalies pass through the one or more light beams will light be scattered toward the camera so that flaws are seen as lighted areas on a normally dark image. The far dark field technique is a species of dark field illumination. Another species is near dark field. The near and far designations refer to the angle incident the plane of the surface being illuminated.

Each of these illumination techniques has some advantages for highlighting certain types of anomalies on structured optical films, but there are some defects that resist detection with one or the other of these methods.

SUMMARY

It has been discovered that a lighting configuration can be prepared that combines the diffuse transmitted lighting technique with at least one further lighting technique as a single station monitored by a single imaging camera. In one embodiment, the further lighting technique is the far dark field lighting source. In certain embodiments this combined illumination technique may provide for more robust detection of anomalies than either illumination technique alone. Instances of anomalies that are negligibly or marginally detectable with either single approach may become enhanced such that they are readily detectable.

In various embodiments, the invention may be directed to any or all of the following:

1. A system for illuminating a transparent or semi-transparent structured sheet material for inspection by an optical receiving device, said sheet material having a first side and a second side, comprising:

- a first light source directing diffuse light through a portion of the sheet material;
- and,

- a second light source directing light toward the same portion of the sheet material concurrently with the first light source.

2. The system embodiment 1, wherein the first side and second side are structured.

3. The system of embodiment 1, wherein the structured sheet material has internal structures.

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4. The illumination system of embodiment 1, wherein the first side is structured.

5. The system according to any embodiment above, wherein the first light source directs light toward the first side of the sheet material, and the optical receiving device is situated to receive light from the second side of the sheet material.

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6. The system according to any embodiment above, wherein the sheet material is a structured optical film.

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7. The system according to any embodiment above, wherein the structured optical film is a prismatic film.

8. The system according to any embodiment above, further comprising:
a third light source directing light toward the same portion of the sheet material concurrently with the first light source and the second light source.

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9. The system of embodiment 8, further comprising:
a fourth light source directing light toward the same portion of the sheet material concurrently with the first light source, the second light source, and the third light source.

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10. The system of embodiment 9, further comprising:
a fifth light source directing light toward the same portion of the sheet material concurrently with the first light source, the second light source, the third light source, and the fourth light source.

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11. The system of embodiment 10, further comprising:

one or more further light sources directing light toward the same portion of the sheet material concurrently with the first light source, the second light source, the third light source, the fourth light source, or the fifth light source.

5 12. The system according to any embodiment above, wherein the first light source directs diffuse light on the side of the web opposed to the optical receiving device.

13. The system according to any embodiment above, wherein the second light source provides far dark field light on the side of the web opposed to the optical receiving device.

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14. The system according to any embodiment above, wherein the first light source directs diffuse light on the side of the web opposed to the optical receiving device, the second light source directs dark field transmitted light on the side of the web opposed to the optical receiving device, and the third light source directs either dark field transmitted
15 light or dark field reflected light

15. A system for inspecting an optical film comprising:

a light sensing apparatus situated to sense light from an inspection area of a surface of an optical film;

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a first light source directing diffuse transmitted light through the web in the inspection area of the web, and into the light sensing apparatus, said first lighting source providing light at a first angle relative to the machine direction of the web;

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a second lighting source directing light toward the inspection area of the web, said second lighting source providing light at a second angle relative to the machine direction of the web, said second angle being other than the first angle.

16. The system of embodiment 15, wherein the light sensing apparatus is a camera.

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17. The system of embodiment 15-16, wherein the light sensing apparatus is a line scan camera.

18. The system of embodiment 15-17, wherein the optical film is moving relative to any or all of: the light sensing apparatus, the first light source, and the second light source.

19. The system of embodiment 15-18, wherein the system inspects the optical film while the optical film is being manufactured.

20. The system of embodiment 15-19, further comprising:

a third lighting source directing light toward the inspection area, said third lighting source providing light at a third angle relative to the machine direction of the web, said third angle being other than the first or second angle.

21. The system of claim 20, further comprising:

one or more further lighting sources directing light toward the inspection area, said one or more further lighting sources providing light at angles, relative to the direction of the web, other than angles of other lighting sources.

22. A method of illuminating a transparent or semi-transparent structured sheet material, comprising:

providing a first lighting source, said first lighting source directing diffuse light through a portion of the sheet material; and

providing a second lighting source, said second lighting source directing light toward the same portion of the sheet material concurrently with the first light source.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic side view of an inspection station.

FIG. 2 is a schematic side view of an inspection station.

FIG. 3A through FIG. 3C are screen prints of the computer screen showing three separate passes of the same portion of the web arranged side by side.

DETAILED DESCRIPTION

Structured optical films, as the term is used herein, refers to films of light-transmissible material in which a series of prisms are disposed on or within the film such that the films can redirect light through reflection or refraction. Structured optical films are described generally in U.S. Pat. No. 4,906,070 (Cobb).

Brightness enhancing film, as the term is used herein, refers to a type of film that can increase the apparent on-axis brightness of Lambertian backlights such as ones commonly used with liquid crystal displays (LCDs). Brightness enhancing films may be structured optical films. An exemplary brightness enhancing film is described in U.S. Pat. No. 5,917,664 (O'Neill). Brightness enhancing films in one embodiment may include micro replicated prisms oriented parallel to one another in the machine direction, and possibly include defect masking patterns, which may involve intentional random or pseudo-random variation in the micro replicated prisms. An exemplary defect masking pattern is described in U.S. Pat. No. 6,354,709 (Campbell). Some brightness enhancing films appear increasingly opaque when viewed at an angle substantially perpendicular to the plane of the film (on axis), but less opaque (e.g. partially or fully transparent) when viewed from an angle other than substantially perpendicular. This characteristic lends itself to certain illumination techniques or combinations of illumination techniques, as will be described more fully herein.

On a perfect mirror surface, light incident a given angle reflects at the equivalent angle in the plane of incidence to form the specular beam. On a real surface some of this light will be scattered (absorbed, diffracted, or otherwise directed to an angle outside the specular beam). Particles, scratches, surface roughness, local surface topography, or interfaces between different materials can cause light to scatter. This scattering may be detected by sensing equipment and analyzed to identify anomalies present in optical film. Anomalies, as the term is used herein, refer to areas of film where optical aberrations are present. Common anomalies include scratches, surface roughness, dents, structural aberrations in a micro replicated pattern (if such a pattern is present in the optical film), entrained bubbles, and contamination. These and other anomalies may render optical film unusable for certain applications.

FIG. 1 is a schematic side view of an inspection station wherein a diffuse transmitted light illumination technique is used with a further technique, in this case the

far dark field illumination technique. This combination may, in some embodiments, provide increased contrast of anomalies present on a surface of a film. Further, in some embodiments, this combination of inspection techniques may provide for detection of otherwise undetectable, or difficult-to-detect, anomalies. In further embodiments, this combination may reduce visual noise associated with inspection of certain types of structured optical films.

Web I1 is a light transmissive film. As non limiting examples only, web I1 may be an optical film, a structured optical film, or a brightness enhancing film. As illustrated in FIG. 1, web I1 is in the process of being manufactured, and would move laterally, either from left-to-right or right-to-left, and the direction of this movement would be considered in the “down-web” or “machine” -direction. Though shown and described herein as being manufactured, the illumination and inspection techniques described herein could be similarly employed after the web has been manufactured, for example. Further, though described with respect to illumination and inspection of a continuous or semi-continuous web, as might be encountered in a manufacturing environment, one skilled in the art will recognize that techniques described herein could be scaled up or down as necessary, or modified to suite environments other than manufacturing.

For purposes of illustration within this disclosure (and not limitation), web I1 may be considered a brightness enhancing film. Web I1 includes, in one embodiment, a structured side and a non-structured side. The structured side of web I1, in this example, has micro replicated prisms, and it is this structured side that faces diffuse transmitted light source I3 (the underside surface of web I1 is the structured surface). Light source I3 provides light directed at lens I4, which provides light to diffuser I6. Light source I3, lens I4, and diffuser I6 comprise diffuse transmitted lighting source I9. Diffuse transmitted lighting source I9 is situated roughly on-axis the plane of web I1. Diffuser I6 is situated to illuminate a cross-web-section (referred to hereinafter as the illuminated area of the web) of the structured side of web I1. As one skilled in the art will recognize, there are myriad methods that can be used to provide diffuse illumination other than the example embodiment shown in FIG. 1. For example, light emitting diode (LED) arrays or fluorescent lamps could be used to provide diffused illumination, with or without a diffuser. Situated on the non-structured side of web I1 is lens I7, which receives light transmitted through web I7. Lens I7 passes light to a sensing device, in this case camera

18. Light from diffuser I6 is refracted as it passes through web I1 (a property of some types of brightness enhancing films) such that the illuminated area of the web appears dark from the viewing angle of camera 8 (and so long as camera 8 is within a limited angle of on-axis with the plane of the web). Anomalies passing through the illuminated area of the web tend not to uniformly refract light, and thus may appear brighter than background.

A second illumination technique configuration, in this case far dark field transmitted lighting source I10, is provided by light source I2 and lens I5, which is situated to provide light at an angle of roughly 35 degrees from normal incidence to the web plane. Angles of 5 degrees to 85 degrees have some level of usefulness depending on specific application. Light from the far dark field transmitted lighting source I10 is concentrated, in one embodiment, along the same illuminated area of the web as is illuminated by diffuse transmitted lighting source I9. Far dark field transmitted light tends to highlight anomalies that scatter light in the down-web, or machine, direction. Such anomalies might include variability in micro replicated prisms or patterns, and/or the interface between micro replication and a backing material, or defects in the backing material itself.

The two illumination techniques (diffuse transmitted and far dark field) are thus combined, and a single sensing device, such as a line scan camera, may be configured to receive signals emanating from the illuminated area of the web.

Light sources I2 and I3 may be any device that emits light, such as traditional incandescent, fluorescent, or halogen bulbs; LEDs; or lasers. Alternatively, light source I2 and/or I3 may not generate their own light at all, and instead be conduits of other lighting sources. For example, light source I2 and/or I3 may be so-called "fiber-line lights," which transport light via fiber-optic lines from a separate lighting source (often a separate device located in proximity). In some embodiments, lighting sources I2 and I3 are of different types (one fluorescent, one laser or fiber-line, etc.).

Lens I4 and I5 may be any type of light-focusing or light-concentrating device. In some embodiments, depending on the nature of the light source, lens I4 and I5 may be omitted. In one embodiment, lens I4 and I5 are acrylic cylindrical lenses.

Diffuser I6 may be any device spreads out or scatters light. In one embodiment, diffuser I6 is a piece of opal glass. In another embodiment is a piece of diffusing film

such as any of a variety of polycarbonate films manufactured by General Electric of Fairfield, Connecticut.

Lens I7 may be any type of lens. In one embodiment it is a Schneider Componon f5.6 / 150mm with 85mm extension tubes.

5 FIG. 2 is a schematic side view of an inspection station wherein diffuse transmitted light illumination technique is used with further illumination techniques. FIG. 2 includes the same components as FIG. 1, but additionally includes another far dark field transmitted lighting source (J1) and a darkfield reflected lighting source (J2). Among other things, FIG. 2 demonstrates that more than just two different illumination techniques
10 may be optically combined and sensed with a single camera or within a single inspection station. In this case, for example, all four lighting sources illustrated in FIG. 3 concentrate light on the same illuminated section of the web that is inspected by camera 8. Further illumination techniques employing more than four illumination techniques could similarly be employed.

15 The second far dark field transmitting light source (J1) may aid the first in highlighting web anomalies as they pass through the illuminated area of the web. The second far dark field transmitting light source is configured generally in the same manner as the first but, in one embodiment, is at the opposing angle. Darkfield reflected lighting source (J2) tends to particularly highlight anomalies on the planar surface of the backing
20 web (non-structured side of web).

 The combination of multiple illumination techniques may facilitate superior automated web inspection. This superiority may be the result of the illumination technique providing adequate signal-to-noise contrast for a wide range of anomalies occurring in a variety of directions and on different surfaces or surface interfaces. Further,
25 the combination of multiple illumination techniques may also increase the signal-to-noise ratio for a higher proportion of defects than any of the combined illumination techniques alone. For example, for a particular defect, diffuse transmitted light source I3 may generate 75% of the resultant signal, while, the case of an inspection station as illustrated in FIG. 2, the two additional far dark field lighting sources may add the remaining 25%,
30 thus providing sufficient signal to isolate an anomalous regions. In another example, the transmitted light source I9 may generate 35% of the resultant signal, while, in the case of

an inspection station as illustrated in FIG. 2, the two additional far dark field lighting sources (J1 and J2) may add the remaining 65%.

Also, multiple lighting techniques may, in some embodiments, serve to reduce inherent noise associated with inspecting a web. For example, some optical films such as brightness enhancing films may include defect masking patterns or other intentional random or psuedo-random variation in a film's properties (such as prism dimension or orientation). When illuminated using a single illumination technique, these intentional film variations may appear as background noise, and thereby reduce contrast of actual anomalies. Multiple illumination techniques, however, may reduce the background noise associated with such intentional film variations and thereby increase the signal-to-noise ratio.

Example

A web inspection station was constructed generally as depicted in FIG. 2. The illumination system was mounted below the web path of a conventional web-handling system on a free span between idler rollers. An AVIIVA™ CCD monochrome linescan camera, commercially available from Atmel of San Jose, CA, equipped with a conventional 150 mm lens, was mounted above illumination system, 83 cm above the web path. The illumination system included three light sources, each included a fiber light line commercially available from Fostec Imaging of San Diego, CA, driven by a Model 4900 Auto-Calibrating Light Source commercially available from Illumination Technologies of East Syracuse, NY. The direct source was aimed directly upwards towards the camera, while the two far dark field sources were aimed at an angle 40 degrees from the vertical. All three sources were otherwise oriented with their long axes parallel to the cross web direction.

Each of the three sources was provided with a cylindrical lens, each made from optically clear acrylic polymer, 1.25 inch (31.75 mm) in diameter. An aluminum frame having a 0.5 inch (12.5 mm) wide slot was mounted between the direct source and the underside of the web such that light from the direct source passed through one of the cylindrical lenses and then through the slot on its way to the underside of the web. A translucent film of matte finished diffuser was placed across the top of the slot.

The output of the camera was directed to a personal computer for analysis. This computer was running the Matrox Inspector 2.2 software package, commercially available from Matrox Imaging of Dorval, Quebec, Canada.

The web inspection station was used to inspect 7 mm thick optical quality prismatic optical film with intentional property variation of the sort that might be used in the manufacture of a variety of products. The particular roll of material for the experiment was chosen because it showed a variety of possible flaws, all the way from gross defects like gouges and surface contamination with sizes ranging from one to several hundred microns, to very fine scratches with widths of approximately 15 to 20 microns.

FIG. 3A through FIG. 3C are screen prints of the computer screen showing three separate passes of the same portion of the web arranged side by side. FIG. 3A is a scan of a length of film illuminated only via a diffuse transmitted light source. The figure shows gradual, "blotchy," grayscale color variation. It is difficult to identify anomalies due to the subtle background noise resulting from intentional film property variation. FIG. 3B is a scan of a length of film illuminated only with far dark field lighting sources. Whereas FIG. 3A has gradual, subtle signal variations, FIG. 3B has clearer, sharper signal variations (many resulting from the same intentional film property variation). As in FIG. 3A, it is similarly difficult for to identify an anomaly against the background noise associated with intentional film property variations. FIG. 3C is a scan of the length of material simultaneously illuminated by both the technique represented in FIG. 3A, and the technique represented in FIG. 3B. Relative to FIG. 3A and FIG. 3B, anomalies such as anomaly D1 are more clearly distinguished, and background noise has been reduced. It will be appreciated from the Figure that there is a significant synergistic effect associated with the illumination system of the present invention: the novel system highlighted not only all the flaws that the more conventional illumination methods alone did, but other, less distinguishable flaws as well.

Table 1 shows relative contributions from three illumination techniques on relatively uniformly structured prismatic film. The Y axis specifies the illumination technique. Cross-groove / down-groove refers to the orientation of test anomalies relative to groove patterns on a structured side of a film.

		Cross-Groove			Down-Groove		
	Background	Signal	Signal – Noise	% Increase from Diffuse Alone	Signal	Signal – Noise	% increase from Diffuse Alone
Diffuse Alone	90	94	4	-	114	24	-
Diffuse + Reflected	96	114	18	350%	125	29	21%
Diffuse + Far Dark Field	98	114	16	300%	137	39	63%
Reflected Alone	4	12	8	100%	20	16	-33%
Reflected + Far Dark Field	11	43	32	700%	35	24	0%
Far Dark Field Alone	6	20	14	250%	22	16	-33%
Diffuse + Reflected + Far Dark Field	103	143	40	900%	153	50	108%

TABLE 1

Table 2 shows relative contributions from three illumination techniques on pseudo-randomly patterned prismatic film.

		Cross-Groove			Down-Groove		
	Background	Signal	Signal – Noise	% Increase from Diffuse Alone	Signal	Signal – Noise	% increase from Diffuse Alone
Diffuse Alone	87	100	13	-	119	32	-
Diffuse + Reflected	93	133	40	208%	137	44	38%
Diffuse + Far Dark Field	90	117	27	108%	148	58	81%
Reflected Alone	9	33	24	85%	19	10	-69%
Reflected + Far Dark Field	17	67	50	285%	43	26	-19%
Far Dark Field Alone	8	25	17	31%	25	17	-47%
Diffuse + Reflected + Far Dark Field	103	163	60	362%	173	70	119%

CLAIMS

1. A system for illuminating a transparent or semi-transparent structured sheet material for inspection by an optical receiving device, said sheet material having a first side and a second side, comprising:

a first light source directing diffuse light through a portion of the sheet material; and,

a second light source directing light toward the same portion of the sheet material concurrently with the first light source.

2. The system of claim 1, wherein the first side and second side are structured.

3. The system of claim 1, wherein the structured sheet material has internal structures.

4. The illumination system of claim 1, wherein the first side is structured.

5. The system of claim 4, wherein the first light source directs light toward the first side of the sheet material, and the optical receiving device is situated to receive light from the second side of the sheet material.

6. The system of claim 1, wherein the sheet material is a structured optical film.

7. The system of claim 6, wherein the structured optical film is a prismatic film.

8. The system of claim 4, further comprising:

a third light source directing light toward the same portion of the sheet material concurrently with the first light source and the second light source.

9. The system of claim 8, further comprising:

a fourth light source directing light toward the same portion of the sheet material concurrently with the first light source, the second light source, and the third light source.

10. The system of claim 9, further comprising:

a fifth light source directing light toward the same portion of the sheet material concurrently with the first light source, the second light source, the third light source, and the fourth light source.

11. The system of claim 10, further comprising:

one or more further light sources directing light toward the same portion of the sheet material concurrently with the first light source, the second light source, the third light source, the fourth light source, or the fifth light source.

12. The system of claim 1, wherein the first light source directs diffuse light on the side of the web opposed to the optical receiving device.

13. The system of claim 12, wherein the second light source provides far dark field light on the side of the web opposed to the optical receiving device.

14. The system of claim 4, wherein the first light source directs diffuse light on the side of the web opposed to the optical receiving device, the second light source directs dark field transmitted light on the side of the web opposed to the optical receiving device, and the third light source directs either dark field transmitted light or dark field reflected light

15. A system for inspecting an optical film comprising:

a light sensing apparatus situated to sense light from an inspection area of a surface of an optical film;

a first light source directing diffuse transmitted light through the web in the inspection area of the web, and into the light sensing apparatus, said first lighting source providing light at a first angle relative to the machine direction of the web;

a second lighting source directing light toward the inspection area of the web, said second lighting source providing light at a second angle relative to the machine direction of the web, said second angle being other than the first angle.

16. The system of claim 15, wherein the light sensing apparatus is a camera.

17. The system of claim 16, wherein the light sensing apparatus is a line scan camera.

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18. The system of claim 15, wherein the optical film is moving relative to any or all of: the light sensing apparatus, the first light source, and the second light source.

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19. The system of claim 16, wherein the system inspects the optical film while the optical film is being manufactured.

20. The system of claim 16, further comprising:

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a third lighting source directing light toward the inspection area, said third lighting source providing light at a third angle relative to the machine direction of the web, said third angle being other than the first or second angle.

21. The system of claim 20, further comprising:

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one or more further lighting sources directing light toward the inspection area, said one or more further lighting sources providing light at angles, relative to the direction of the web, other than angles of other lighting sources.

22. A method of illuminating a transparent or semi-transparent structured sheet material, comprising:

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providing a first lighting source, said first lighting source directing diffuse light through a portion of the sheet material; and

providing a second lighting source, said second lighting source directing light toward the same portion of the sheet material concurrently with the first light source.