



US006624597B2

(12) **United States Patent**
Dowling et al.

(10) **Patent No.:** **US 6,624,597 B2**
(45) **Date of Patent:** **Sep. 23, 2003**

(54) **SYSTEMS AND METHODS FOR PROVIDING ILLUMINATION IN MACHINE VISION SYSTEMS**

(75) Inventors: **Kevin J. Dowling**, Westford, MA (US); **George G. Mueller**, Boston, MA (US); **Ihor A. Lys**, Boston, MA (US)

(73) Assignee: **Color Kinetics, Inc.**, Boston, MA (US)

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

(21) Appl. No.: **09/944,523**

(22) Filed: **Aug. 31, 2001**

(65) **Prior Publication Data**

US 2002/0101200 A1 Aug. 1, 2002

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/669,121, filed on Sep. 25, 2000, which is a continuation of application No. 09/425,770, filed on Oct. 22, 1999, now Pat. No. 6,150,774, which is a continuation of application No. 08/920,156, filed on Aug. 26, 1997, now Pat. No. 6,016,038, application No. 09/944,523, which is a continuation-in-part of application No. 09/815,418, filed on Mar. 22, 2001, which is a continuation of application No. 09/213,548, filed on Dec. 17, 1998, now Pat. No. 6,166,496, application No. 09/944,523, which is a continuation-in-part of application No. 09/742,017, filed on Dec. 20, 2000, which is a continuation of application No. 09/213,548, application No. 09/944,523, which is a continuation-in-part of application No. 09/626,905, filed on Jul. 27, 2000, which is a continuation of application No. 09/213,659, filed on Dec. 17, 1998, now Pat. No. 6,211,626, application No. 09/944,523, which is a continuation-in-part of application No. 09/333,739, filed on Jun. 15, 1999, and a continuation-in-part of application No. 09/215,624, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,607, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,581, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,540, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,540, filed on Dec. 17, 1998.

(60) Provisional application No. 60/229,849, filed on Sep. 1, 2000, provisional application No. 60/090,920, filed on Jun. 26, 1998, provisional application No. 60/079,285, filed on Mar. 25, 1998, provisional application No. 60/078,861, filed on Mar. 20, 1998, provisional application No. 60/068,792, filed on Dec. 24, 1997, and provisional application No. 60/071,281, filed on Dec. 17, 1997.

(51) **Int. Cl.⁷** **G05F 1/00**
(52) **U.S. Cl.** **315/291; 315/294; 315/312; 315/362; 250/227.29**

(58) **Field of Search** 315/291, 292, 315/294, 297, 300, 302, 307, 312, 360, 362, 76; 257/88, 89; 250/227.29, 234, 578.1

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,909,097 A 10/1959 Alden et al.
3,318,185 A 5/1967 Kott

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

AU 6 267 9 12/1996
CA 2 178 432 12/1996

(List continued on next page.)

OTHER PUBLICATIONS

Patent Abstract of Japan, Publication No. 06066534, published Mar. 8, 1994.

(List continued on next page.)

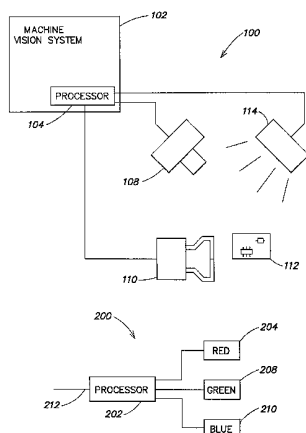
Primary Examiner—Haissa Philogene

(74) *Attorney, Agent, or Firm*—Wolf, Greenfield & Sacks, P.C.

(57) **ABSTRACT**

One embodiment is a lighting system associated with a machine vision system. The machine vision system may direct lighting control commands to the lighting system to change the illumination conditions provided to an object. A vision system may also be provided and associated with the machine vision system such that the vision system views and captures an image(s) of the object when lit by the lighting system. The machine vision system may direct the lighting system to change the illumination conditions and then capture the image.

31 Claims, 3 Drawing Sheets



U.S. PATENT DOCUMENTS					
3,561,719 A	2/1971	Grindle	5,078,039 A	1/1992	Tulk et al.
3,586,936 A	6/1971	McLeroy	5,083,063 A	1/1992	Brooks
3,601,621 A	8/1971	Ritchie	5,095,204 A *	3/1992	Novini 250/223 B
3,643,088 A	2/1972	Osteen et al.	5,126,634 A	6/1992	Johnson
3,746,918 A	7/1973	Drucker et al.	5,128,595 A	7/1992	Hara
3,818,216 A	6/1974	Larraburu	5,134,387 A	7/1992	Smith et al.
3,832,503 A	8/1974	Crane	5,142,199 A	8/1992	Elwell
3,858,086 A	12/1974	Anderson et al.	5,154,641 A	10/1992	McLaughlin
3,909,670 A	9/1975	Wakamatsu et al.	5,164,715 A	11/1992	Kashiwabara et al.
3,924,120 A	12/1975	Cox, III	5,166,985 A	11/1992	Takagi et al.
3,958,885 A	5/1976	Stockinger et al.	5,172,005 A *	12/1992	Cochran et al. 250/559.08
3,974,637 A	8/1976	Bergey et al.	5,184,114 A	2/1993	Brown
4,001,571 A	1/1977	Martin	5,194,854 A	3/1993	Havel
4,054,814 A	10/1977	Fegley et al.	5,209,560 A	5/1993	Taylor et al.
4,082,395 A	4/1978	Donato et al.	5,225,765 A	7/1993	Callahan et al.
4,096,349 A	6/1978	Donato	5,226,723 A	7/1993	Chen
4,241,295 A	12/1980	Williams, Jr.	5,254,910 A	10/1993	Yang
4,272,689 A	6/1981	Crosby et al.	5,256,948 A	10/1993	Boldin et al.
4,273,999 A	6/1981	Pierpoint	5,282,121 A	1/1994	Bornhorst et al.
4,298,869 A	11/1981	Okuno	5,294,865 A	3/1994	Haraden
4,329,625 A	5/1982	Nishizawa et al.	5,300,788 A *	4/1994	Fan et al. 257/13
4,367,464 A	1/1983	Kurahashi et al.	5,307,295 A	4/1994	Taylor et al.
4,388,567 A	6/1983	Yamazaki et al.	5,329,431 A	7/1994	Taylor et al.
4,388,589 A	6/1983	Moldrem, Jr.	5,350,977 A	9/1994	Hamamoto et al.
4,392,187 A	7/1983	Bornhorst	5,357,170 A	10/1994	Luchaco et al.
4,420,711 A	12/1983	Takahashi et al.	5,369,492 A	11/1994	Sugawara
4,500,796 A	2/1985	Quin	5,371,618 A	12/1994	Tai et al.
4,622,881 A	11/1986	Rand	5,374,876 A	12/1994	Horibata et al.
4,625,152 A	11/1986	Nakai	5,388,357 A	2/1995	Malita
4,635,052 A	1/1987	Aoike et al.	5,402,702 A	4/1995	Hata
4,647,217 A	3/1987	Havel	5,404,282 A	4/1995	Klinke et al.
4,656,398 A	4/1987	Michael et al.	5,406,176 A	4/1995	Sugden
4,668,895 A	5/1987	Schneiter	5,410,328 A	4/1995	Yoksa et al.
4,682,079 A	7/1987	Sanders et al.	5,412,284 A	5/1995	Moore et al.
4,686,425 A	8/1987	Havel	5,412,552 A	5/1995	Fernandes
4,687,340 A	8/1987	Havel	5,420,482 A	5/1995	Phares
4,688,154 A	8/1987	Nilssen	5,421,059 A	6/1995	Leffers, Jr.
4,688,869 A	8/1987	Kelly	5,432,408 A	7/1995	Matsuda et al.
4,695,769 A	9/1987	Schweickardt	5,436,535 A	7/1995	Yang
4,701,669 A	10/1987	Head et al.	5,461,188 A	10/1995	Drago et al.
4,705,406 A	11/1987	Havel	5,463,280 A	10/1995	Johnson
4,707,141 A	11/1987	Havel	5,465,144 A	11/1995	Parker et al.
4,727,289 A	2/1988	Uchida	5,489,827 A	2/1996	Xia
4,740,882 A	4/1988	Miller	5,491,402 A	2/1996	Small
4,753,148 A	6/1988	Johnson	5,504,395 A	4/1996	Johnson et al.
4,771,274 A	9/1988	Havel	5,545,950 A	8/1996	Cho
4,780,621 A	10/1988	Bartleucci et al.	5,561,346 A	10/1996	Byrne
4,818,072 A	4/1989	Mohebban	5,575,459 A	11/1996	Anderson
4,837,565 A	6/1989	White	5,575,554 A	11/1996	Guritz
4,843,627 A	6/1989	Stebbins	5,592,051 A	1/1997	Korkala
4,845,481 A	7/1989	Havel	5,640,061 A	6/1997	Bornhorst et al.
4,845,745 A	7/1989	Havel	5,642,129 A	6/1997	Zavracky et al.
4,863,223 A	9/1989	Weissenbach et al.	5,673,059 A	9/1997	Zavracky et al.
4,874,320 A	10/1989	Freed et al.	5,701,058 A	12/1997	Roth
4,887,074 A	12/1989	Simon et al.	5,721,471 A	2/1998	Begemann et al.
4,922,154 A	5/1990	Cacoub	5,734,590 A	3/1998	Tebbe
4,934,852 A	6/1990	Havel	5,751,118 A	5/1998	Mortimer
4,962,687 A	10/1990	Belliveau et al.	5,752,766 A	5/1998	Bailey et al.
4,965,561 A	10/1990	Havel	5,769,527 A	6/1998	Taylor et al.
4,973,835 A	11/1990	Kurosu et al.	5,803,579 A	9/1998	Turnbull et al.
4,979,081 A	12/1990	Leach et al.	5,808,689 A	9/1998	Small
4,980,806 A	12/1990	Taylor et al.	5,821,695 A	10/1998	Vilanilam et al.
4,992,704 A	2/1991	Stinson	5,848,837 A	12/1998	Gustafson
5,003,227 A	3/1991	Nilssen	5,850,126 A	12/1998	Kanbar
5,008,595 A	4/1991	Kazar	5,851,063 A	12/1998	Doughty et al.
5,010,459 A	4/1991	Taylor et al.	5,852,658 A	12/1998	Knight et al.
5,027,262 A	6/1991	Freed	RE36,030 E	1/1999	Nadeau
5,034,807 A	7/1991	Von Kohorn	5,859,508 A	1/1999	Ge et al.
5,060,065 A	10/1991	Wasserman	5,896,010 A	4/1999	Mikolajczak et al.
5,072,216 A	12/1991	Grange	5,912,653 A	6/1999	Fitch
			5,924,784 A	7/1999	Chliwnyj et al.

5,946,209	A	8/1999	Eckel et al.
5,952,680	A	9/1999	Strite
5,959,547	A	9/1999	Tubel et al.
5,963,185	A	10/1999	Havel
5,974,553	A	10/1999	Gandar
6,008,783	A	12/1999	Kitagawa et al.
6,016,038	A	1/2000	Mueller et al.
6,018,237	A	1/2000	Havel
6,025,550	A	2/2000	Kato
6,031,343	A	2/2000	Recknagel et al.
6,068,383	A	5/2000	Robertson et al.
6,072,280	A	6/2000	Allen
6,095,661	A	8/2000	Lebens et al.
6,097,352	A	8/2000	Zavracky et al.
6,132,072	A	10/2000	Turnbull et al.
6,135,604	A	10/2000	Lin
6,150,774	A	11/2000	Mueller et al.
6,166,496	A	12/2000	Lys et al.
6,183,086	B1	2/2001	Neubert
6,184,628	B1	2/2001	Ruthenberg
6,196,471	B1	3/2001	Ruthenberg
6,211,626	B1	4/2001	Lys et al.
6,215,409	B1	4/2001	Blach
6,250,774	B1	6/2001	Begemann et al.
6,292,901	B1	9/2001	Lys et al.
6,340,868	B1	1/2002	Lys et al.
6,459,919	B1	10/2002	Lys et al.
2001/0033488	A1	10/2001	Chliwnyj et al.

FOREIGN PATENT DOCUMENTS

EP	0443289	8/1991
EP	0452905 A1	10/1991
EP	0495305 A2	7/1992
EP	0534710 B1	1/1996
EP	0752632 A2	1/1997
EP	0752632 A3	8/1997
EP	0823812 A2	2/1998
EP	0935234 A1	8/1999
EP	0942631 A2	9/1999
EP	1020352 A2	7/2000
EP	1113215 A2	7/2001
FR	88 17359	12/1998

GB	2045098 A	10/1980
GB	2135536 A	8/1984
GB	2176042 A	12/1986
JP	06043830	2/1994
JP	7-39120	7/1995
JP	8-106264	4/1996
JP	9 320766	12/1997
WO	WO 89/05086	6/1989
WO	WO 94/18809	8/1994
WO	WO 95/13498	5/1995
WO	WO 96/41098	12/1996

OTHER PUBLICATIONS

“LM117/LM317A/LM317 3-Terminal Adjustable Regulator”, National Semiconductor Corporation, May 1997, pp. 1-20.

“DS96177 RS-485 / RS-422 Differential Bus Repeater”, National Semiconductor Corporation, Feb. 1996, pp. 1-8.

“DS2003 / DA9667 / DS2004 High Current / Voltage Darlington Drivers”, National Semiconductor Corporation, Dec. 1995, pp. 1-8.

“LM140A / LM140 / LM340A / LM7800C Series 3—Terminal Positive Regulators”, National Semiconductor Corporation, Jan. 1995, pp. 1-14.

High End Systems, Inc., Trackspot User Manual, Aug. 1997, Excerpts (Cover, Title page, pp. ii through iii and 2-13 through 2-14).

Artistic License, AL4000 DMX512 Processors, Revision 3.4, Jun. 2000, Excerpts (Cover, pp. 7,92 through 102).

Artistic License, Miscellaneous Drawings (3 sheets) Jan. 12, 1995.

Artistic License, Miscellaneous Documents (2 sheets Feb. 1995 and Apr. 1996).

Newnes’s Dictionary of Electronics, Fourth Edition, S.W. Amos, et al., Preface to First Edition, pp. 278-279.

“<http://www.luminus.cx/projects/chaser>”, (Nov. 13, 2000), pp. 1-16.

* cited by examiner

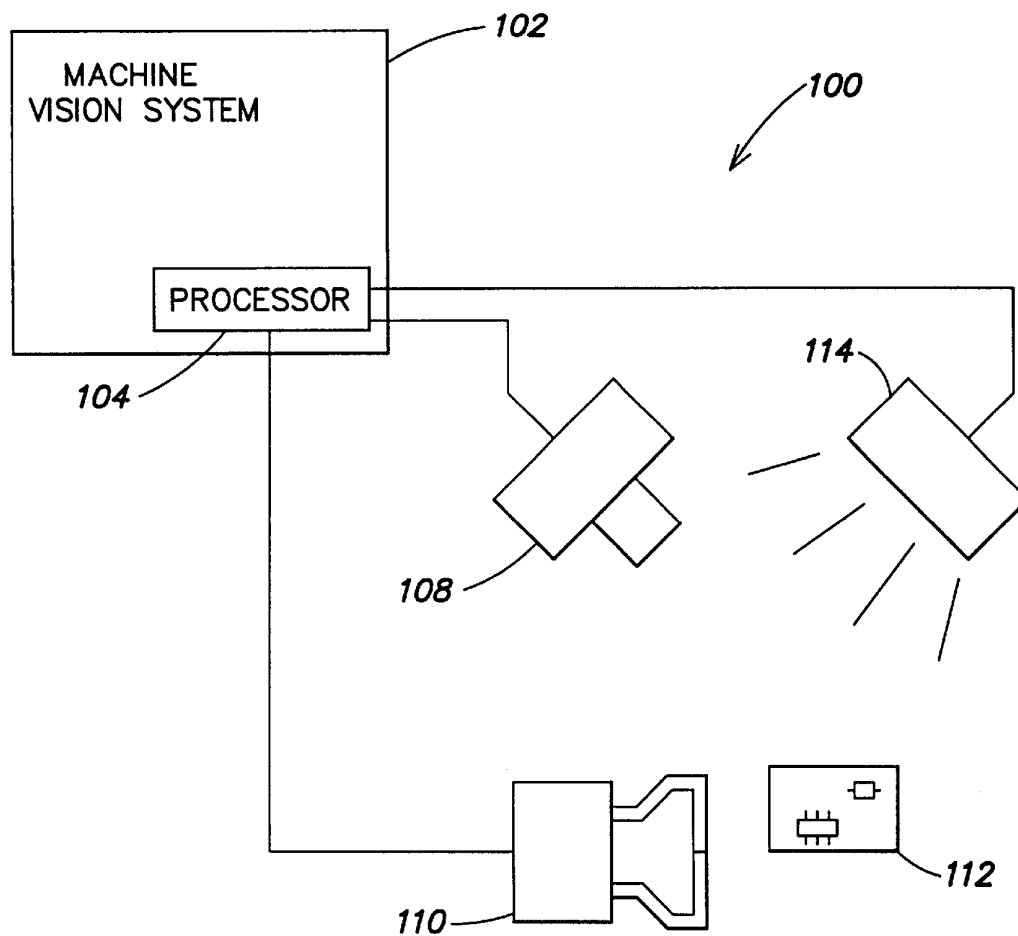


FIG. 1

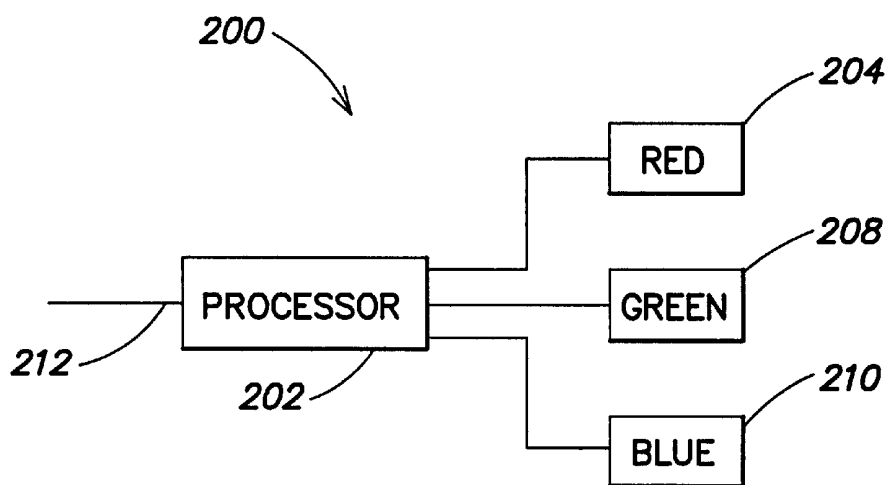


FIG. 2

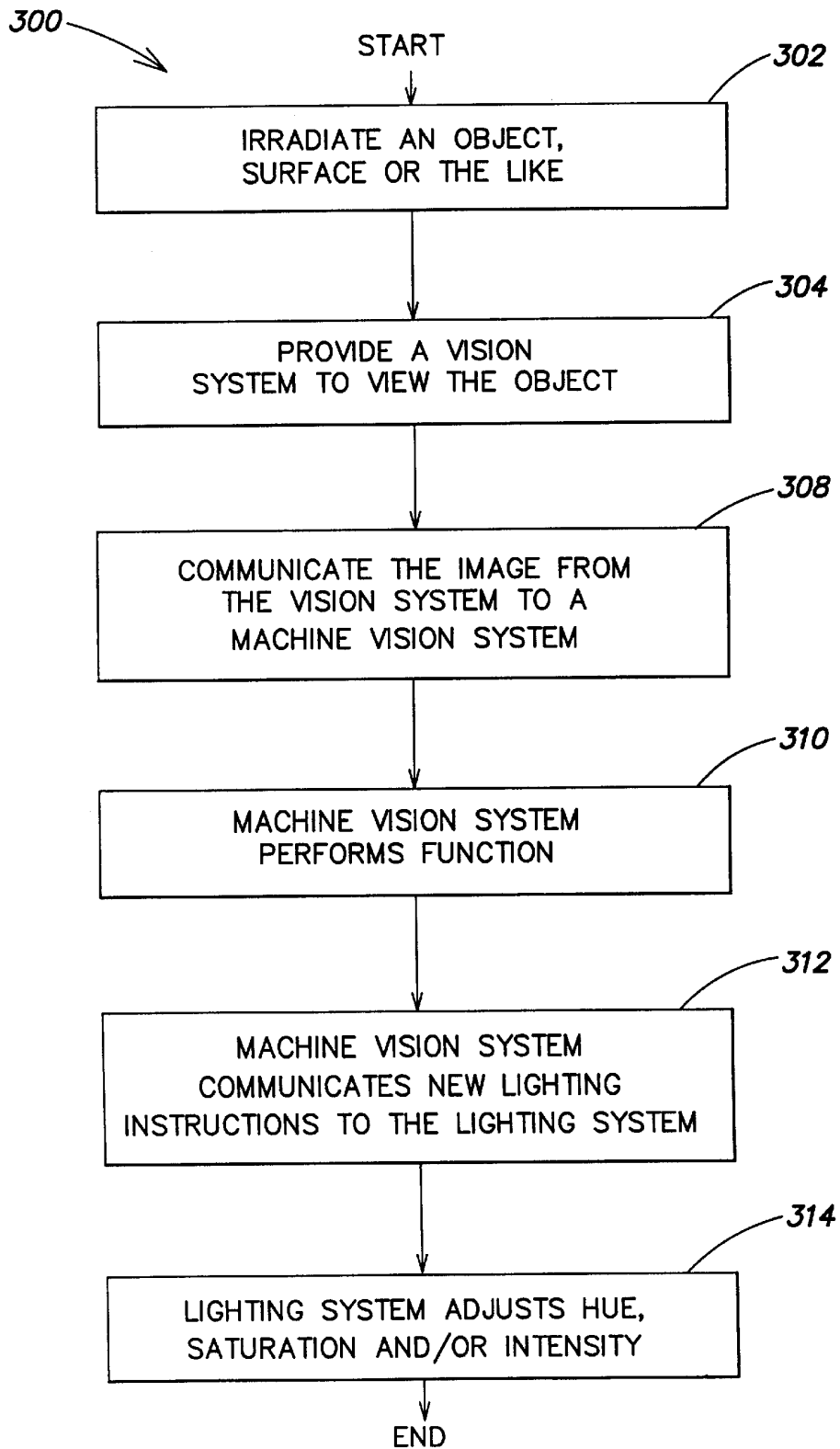


FIG. 3

**SYSTEMS AND METHODS FOR PROVIDING
ILLUMINATION IN MACHINE VISION
SYSTEMS**

RELATED APPLICATIONS

This Application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Patent Application Ser. No. 60/229,849, filed Sep. 1, 2000, entitled "Machine Vision".

This application also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of U.S. Non-provisional application Ser. No. 09/669,121, filed Sep. 25, 2000, entitled "Multicolored LED Lighting Method and Apparatus", which is a continuation of U.S. Ser. No. 09/425,770, filed Oct. 22, 1999, now U.S. Pat. No. 6,150,774, which is a continuation of U.S. Ser. No. 08/920,156, filed Aug. 26, 1997, now U.S. Pat. No. 6,016,038.

This application also claims the benefit under 35 U.S.C. §120 as a continuation-in-part (CIP) of the following U.S. Non-provisional Applications:

Ser. No. 09/215,624, filed Dec. 17, 1998, entitled "Smart Light Bulb";

Ser. No. 09/213,607, filed Dec. 17, 1998, entitled "Systems and Methods for Sensor-Responsive Illumination";

Ser. No. 09/213,189, filed Dec. 17, 1998, entitled "Precision Illumination";

Ser. No. 09/213,581, filed Dec. 17, 1998, entitled "Kinetic Illumination";

Ser. No. 09/213,540, filed Dec. 17, 1998, entitled "Data Delivery Track";

Ser. No. 09/333,739, filed Jun. 15, 1999, entitled "Diffuse Illumination Systems and Methods";

Ser. No. 09/742,017, filed Dec. 20, 2000, entitled "Lighting Entertainment System", which is a continuation of U.S. Ser. No. 09/213,548, filed Dec. 17, 1998, now U.S. Pat. No. 6,166,496;

Ser. No. 09/815,418, filed Mar. 22, 2001, entitled "Lighting Entertainment System", which also is a continuation of U.S. Ser. No. 09/213,548, filed Dec. 17, 1998, now U.S. Pat. No. 6,166,496; and

Ser. No. 09/626,905, filed Jul. 27, 2000, entitled "Lighting Components", which is a continuation of U.S. Ser. No. 09/213,659, filed Dec. 17, 1998, now U.S. Pat. No. 6,211,626.

This application also claims the benefit under 35 U.S.C. §120 of each of the following U.S. Provisional Applications, as at least one of the above-identified U.S. Non-provisional Applications similarly is entitled to the benefit of at least one of the following Provisional Applications:

Serial No. 60/071,281, filed Dec. 17, 1991, entitled "Digitally Controlled Light Emitting Diodes Systems and Methods";

Serial No. 60/068,792, filed Dec. 24, 1997, entitled "Multi-Color Intelligent Lighting";

Serial No. 60/078,861, filed Mar. 20, 1998, entitled "Digital Lighting Systems";

Serial No. 60/079,285, filed Mar. 25, 1998, entitled "System and Method for Controlled Illumination"; and

Serial No. 60/090,920, filed Jun. 26, 1998, entitled "Methods for Software Driven Generation of Multiple Simultaneous High Speed Pulse Width Modulated Signals".

Each of the foregoing applications is hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to machine vision systems. More particularly, this invention relates to lighting systems for machine vision systems.

2. Description of Related Art

Machine vision systems have been in use for many years. These systems are designed to remove the human element from the manufacturing and inspection process. Many manufacturing and inspection operations are not necessarily difficult but they are boring. It is the boredom of these tasks that causes people to become unfocused during the operation, leading to defects in the product.

Vision systems traditionally have used monochrome or gray scale systems to capture the images of objects. These systems typically view the object through a video camera to determine particular attributes of the object. The system may be used to determine if a particular attribute is present or if it is properly oriented or located within a predetermined area. These systems may provide feedback during the manufacturing process or they may be used off-line as inspection devices or manufacturing aides. The feedback system may include a computer controlled feedback loop or it may be provided through human interaction. The scales of gray may be appropriate for determining some material attributes such as size, shape or color differences; however, when the degrees of differentiation between similarly colored parts is slight, a color system may be required. Thus, color recognition systems have also been incorporated into machine vision systems for more complex tasks. All of these systems rely on a sensory input device, typically a camera, a processor and a lighting device, to control the lighting of the object to be analyzed. The advent of powerful computing systems has allowed the development of the colored system. These color systems require more computations per second because of the complexity of the system. Many of these systems work on high-speed production lines where any reduction in speed is intolerable, necessitating the need for increased computational power.

Lighting is a vital part of both the gray-scale and color systems. If the lighting does not create the proper contrast or color, the system will slow down, give false indications, or completely fail to operate. Several lighting systems are available for these vision system applications.

Vision systems typically require a light source with full visible-spectrum light emission. The light source produces light and the light is reflected off of an object to be inspected. The sensing system (e.g., camera) collects the reflected light and a processor analyzes the image for color and/or contrast. If the light source does not emit wavelengths compatible with the color of the object, the contrast between the targeted attribute and other attributes will be low. This low contrast can lead to false readings or false indications. To avoid such problems, vision systems generally use light sources that emit light throughout the visible spectrum. These light sources typically do not provide equal amounts of energy throughout the visible spectrum but they do emit some energy throughout most of the spectrum. In the case of an incandescent or halogen source, the red emission is high but the energy level is drastically reduced as the wavelength shortens, so there is very little blue emission. Fluorescent lamps tend to have gaps in the spectral output where there may be little or no emission. Once a light source is selected and the vision system is programmed, it is important that the lighting conditions remain constant. If the lighting conditions change, the reflected light and the resulting image may

also change. Periodic calibrations may be provided to compensate for changing conditions within the light source.

There are several methods for analyzing the reflected light. One such method is referred to as the RGB or red, green, blue method. The RGB method involves representing all colors as a mixture of red, green and blue which constitute the primary colors used by video cameras, televisions, and PC monitors. When combined, these colors can create any color within the visible light spectrum. The second method is referred to as the HIS or hue, saturation and intensity method. HIS is based on how humans perceive color so the method is more intuitive than RGB. The method of data interpretation depends on the complexity of the task. Where coarse degrees of color separation are required, such as when identifying a red component from a green component, the RGB method may be chosen. Where the degrees of color are much finer, such as sorting pharmaceutical tablets or inspecting fruit, the HIS method may be used. Many other methods of data interpretation and manipulation could be used or developed.

Lighting is an integral part of all vision systems and it would be useful to have a lighting system incorporated into the vision system. It would also be useful to have the vision system communicate with the lighting system to create various effects.

SUMMARY OF THE INVENTION

One embodiment of the present invention is directed to a machine vision system comprising a first processor, and a lighting system capable of producing and modulating light, wherein the first processor communicates lighting command signals to the lighting system.

An embodiment of the present invention is directed to a method of lighting an object or surface in a machine vision system. The method comprises acts of providing a machine vision system, providing a lighting system capable of producing and modulating light, and communicating lighting command signals from the machine vision system to the lighting system.

Another embodiment of the present invention is directed to a method of lighting an object or surface in a machine vision system. The method comprises acts of providing a machine vision system that includes an optical system for viewing an object; providing an object; arranging the optical system to view the object; arranging a lighting system to irradiate the object, wherein the lighting system is capable of producing and modulating light; communicating first lighting control commands from the machine vision system to the lighting system; and executing a machine vision function and then having the machine vision system communicate second lighting control commands to the lighting system.

BRIEF DESCRIPTION OF THE DRAWING

The following figures depict certain illustrative embodiments of the invention in which like reference numerals refer to like elements. These depicted embodiments are to be understood as illustrative of the invention and not as limiting in any way.

FIG. 1 illustrates a machine vision system according to one embodiment of the present invention;

FIG. 2 illustrates a lighting system that can be used with the machine system of FIG. 1; and

FIG. 3 illustrates a flow diagram of a lighting process for a machine vision system to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS(S)

The description below pertains to several illustrative embodiments of the invention. These are described merely for illustrative purposes, as the scope of the invention is not to be limited in any way by the disclosure below.

The development of high brightness LEDs and the development of digital lighting technology has created many opportunities for LED lighting. U.S. Pat. Nos. 6,016,038 and 6,211,626 describe many such lighting devices. U.S. Pat. Nos. 6,016,038 and 6,211,626 are hereby incorporated by reference herein. These patents describe methods of controlling the light output from a lighting system comprised of different colored LEDs for example. Embodiments of these patents describe the use of pulse width modulation (PWM) and independent control of the LEDs to produce varying color within a color spectrum.

In one embodiment of the present invention, an LED lighting device with color changing capabilities may be used to illuminate objects in a vision system or machine vision system. The device may be an independently controlled device with operator control or the device could be incorporated into the machine vision system. The lighting device may also be networked to other devices in the manufacturing or inspection system. As an example, an upstream process change may take place and a signal could be sent to the lighting device to change its mode of operation. If the lighting device was incorporated into the vision system, the vision system processor may control the operation of the device. A light detection unit could also be employed to constantly or periodically measure the light output from the lighting device. This information could be used to recalibrate the device for overall intensity or particular wavelengths.

A lighting device according to the principles of the present invention may include two or more different colored LEDs or it could have a single colored LED. The intensities of the respective LEDs could be varied and controlled through pulse width modulation or other LED control techniques. This system may be suited for color changing effects but it may also be used in a constant color mode. This system may be used for vision applications that require fast activation times, such as on a high-speed production line. The LED device can be turned off or the intensity reduced during the periods where the product or objects are being transferred into the vision station and be reactivated during the period of desired exposure. The LED system may also be used for providing saturated colors with high energy at wavelengths where other light sources cannot produce. With red, green and blue LEDs, the high energy can be produced in all three of these areas, as compared with halogen lamps that produce very little radiation in the blue and fluorescent lamps that have gaps in one of these areas. Any variation of hue, saturation, and intensity can be made with a combination of LEDs. The LED control signals can also be adjusted to avoid any mismatch between the video capture rate and the lighting. Another unique attribute of the LED device is that it activates so quickly that the lighting can give a strobing effect. This can be used on continuous flow systems where the strobe rate appears to freeze the objects so they can be viewed. The strobing effect is commonly used where high-speed visualization is required, however, an LED system according to the principles of the present invention can provide strobing in different colors. The rate of strobe and the rate of color change may be independent and may be controlled through the vision system or as an independent device.

Another example of the usefulness of a system according to one embodiment of the present invention is where the vision system needs to recognize several colors. The lighting effects can change as the system recognizes the attributes. If the object being viewed by the system has a blue and red wires that need to be identified, the system can activate the blue LEDs to create contrast between the blue wire and its surroundings and then perform a similar function with the red LEDs activated for the red wire. When only the blue LEDs are on, the blue wire will reflect the light and the red wire will not, enabling the blue wire to be easily identified. This is merely one simple example of an identification method that can be employed using an LED light source—many other recognition patterns are possible. This example serves to illustrate that the lighting effects can quickly and easily be changed to suit the particular application. Techniques using the principles of the present invention may also reduce the undesirable effects caused by uncontrolled changing lighting conditions. The high contrast provided by such a system may reduce or eliminate the need for calibration of the lighting system.

In one embodiment, a lighting system may also be used in conjunction with other lighting devices or filters to create other desired effects. Moving filters can be used with this system and may be desired when the filters create a desired lighting effect and the speed of the system is not as critical.

Another example of the advantages of using a device as described herein is where ultraviolet light is required to image the object or where both ultraviolet and visible or infrared are required. The vision system can be configured to receive the ultraviolet, visible and/or infrared radiation to make these lighting effects useful. The system can then activate the LEDs separately or simultaneously to provide various effects. Many objects reflect or fluoresce under ultraviolet light and thus can be easily identified through ultraviolet irradiation. These effects may be most pronounced when radiation is limited to the ultraviolet and in this case the ultraviolet radiation and identification process could take place before any visible identifications were made. Again, these lighting conditions can be changed almost instantaneously to provide fast system response.

Another method of computer vision involves creating three-dimensional shapes through the analysis of images and shadows cast on the image. The shading produced when an object is illuminated can be used effectively to recover its shape, reflection parameters, and also the direction and characteristics of the light source illuminating it. A lighting system according to the principles of the present invention may be used in such computer vision systems. The addition of color control may also aid in the reconstruction of the surface texture and color. By controlling the wavelength of radiation to more precise limits, the reflectance properties can be better approximated leading to a superior rendition of the surface properties.

FIG. 1 illustrates a machine vision system according to one embodiment of the present invention. In this embodiment, the machine vision system is constructed of several elements such as a lighting system 114, a vision system (e.g., camera) 108, and an assembly apparatus 110. These elements may be considered peripherals to the central machine vision system 102. The machine vision system may include a processor 104 that controls and/or receives data from the peripherals 108, 114, and 110. The vision system 108 may be arranged to view an object 112. The object 112 may be any object, surface, or material and may be the subject of inspection or manufacture by or through the machine vision system. In another embodiment, the machine

vision system 102 may not include assembly apparatus 110, because the primary objective of the system 102 may be inspection rather than assembly.

In one embodiment, the lighting system 114 may be associated with the processor 104 such that the processor directs commands to the lighting system 114 and the lighting system 114 responds by changing the illumination conditions in accordance with the commands. In one embodiment, the lighting system 114 is an LED lighting system 114 and the LED lighting system 114 may receive control signals from the processor 104. For example, the LED lighting system 114 may include one or more LEDs and the processor may generate and communicate control signals to the LED(s). The control signals may be pulse width modulated signals, pulse amplitude modulated signals, pulse displacement modulated signals or other modulated signals. The control signals may also be analog control signals (e.g., voltage, current, power control signals). In another embodiment, the lighting system 114 may include a second processor 202 (FIG. 2) wherein the processor 104 communicates lighting control signals to the second processor 202. The second processor 202 may receive and interpret the lighting control signals and generate lighting element control signals. For example, the processor 104 may communicate lighting control signals indicating a specific value for the hue, saturation and intensity of the light to be generated by the lighting system 114. The second processor 202 may receive the control signals and generate lighting element control signals to control the lighting element(s) of the lighting system 114. In one embodiment, the lighting system 114 may be an LED lighting system 114 wherein the LED lighting system 114 includes a second processor. As shown in FIG. 2, the LED lighting system 114 may also include several LEDs of different colors (e.g., red 204, green 208 and blue 210). The second processor may, for example, control the LEDs independently with pulse width modulated signals to change the light emitted from the lighting system 114.

In one embodiment, the lighting system 200 (FIG. 2) may be included in a lighting system 114, and includes a processor 202 and one or more LEDs 204, 208, 210. The LEDs in this example are illustrated as red 204, green 208, and blue 210, but the LEDs may be any color suitable for the user's task. The processor 202 may include a data input 212. In one embodiment, the machine vision processor 104 may communicate lighting control signals to the lighting system processor 202 through the data input 212. The communication may be accomplished through wired or wireless communication techniques.

The vision system 108 may be a color vision system or a gray scale (e.g., shade of one color) or other system. Changing the lighting conditions on the object 112 can increase the contrast between sections of the object 112 in either a color system or a gray scale system, and as a result, an intelligent lighting system 114 may be useful in either system.

In one embodiment, the lighting system 114 may be capable of producing varying degrees of color (e.g., hue, saturation and intensity) and the color may include ultraviolet spectra, infrared spectra or other spectra. In one embodiment, the lighting system may be an LED lighting system with three colors (e.g., red 204, green 208 and blue 210) and these individual or groups of LEDs may be varied in intensity. As the light from these LEDs combines, a combined color is formed (additive color mixing) and the varied intensities may cause the combined color to change. For example, the machine vision system may be viewing the

object **112** through the vision system **108** wherein the processor **104** is attempting to locate a blue portion of the object **112** (e.g., a wire), so the processor **104** may communicate lighting control signals to the lighting system such that the lighting system produces blue light to increase the contrast between the blue wire and the other portions of the object **112**. In one embodiment, the processor **104** may attempt to find another portion of the object **112** (e.g., a red wire) and the processor **104** may communicate lighting control signals to the lighting system **114** to change the light to red before attempting to locate the red wire to increase the contrast between the red wire and other portions of the object **112**. This is just one example of how a machine vision system **102** with a controllable lighting system **114** according to the principles of the present invention can be used to increase the effectiveness of such a system, and it should be understood that such a system may be used in a variety of ways.

In one embodiment, the machine vision system **102** may be associated with more than one lighting system **114**. More than one lighting systems **114** may be used to light a same object **112**, or the lighting systems **114** may be used to light more than one object **112**. For example, an object **112** may be lit with two or more lighting systems **114** to provide irradiation from different angles or for different cameras **108**. The machine vision system **102** may direct lighting commands to the first lighting system such that the object is lit and the first camera identifies a portion of the object and then the machine vision system may direct a new command to the first lighting system **114** (e.g., turning it off) followed by lighting commands for the second lighting system **114**. In this arrangement, it may be useful to provide addressable processors in the lighting systems **114** such that they can read network commands to simplify the communication system. In another embodiment, it may be desirable to have direct communication from the machine vision system **102** to the lighting systems **114**.

One of the advantages of providing a lighting system **114** that is comprised of LEDs is that the LEDs can react very quickly. The LEDs can produce full output and then return to zero output within frame rates of the vision system. This means an LED lighting system **114** can change the lighting effects or illumination conditions provided to the object **112** within the time it takes the machine vision system to recognize the portion of the object **112** it is attempting to identify. This provides a machine vision system **102** that can change the illumination conditions for each operation it undertakes without slowing the equipment, which can be important in some applications.

Although many of the embodiments herein describe LED lighting systems **114**, in other embodiments the lighting system may be comprised of illumination sources other than LEDs. For example, the lighting system **114** may include a fluorescent, incandescent, halogen, high intensity discharge or other illumination source. In one embodiment, one of these other illumination sources may be combined with LEDs to form the lighting system **114**. For example, the lighting system may be arranged with a halogen illumination source and an LED illumination source such that the machine vision system **102** can direct lighting commands to the lighting system **114** to control the halogen and LED illumination sources.

FIG. 3 is a flow diagram of a process according to one embodiment of the present invention. In this embodiment, the first act **302** is to irradiate an object, surface or the like with light from a lighting system. The lighting system may be capable of changing the properties of the light produced

from the lighting system. A vision system may then be provided to view and capture an image of a portion of the object (act **304**). The illumination conditions provided by the lighting system may be used to alter the image as viewed or captured. The image then may be communicated to a machine vision system in act **308**. The machine vision system may be arranged to then perform an inspection, manipulation or other function (act **310**) and then direct new lighting commands to the lighting system to change the illumination conditions provided to the object (act **314**). In response to the lighting commands, the lighting system may then change the hue, saturation and/or intensity of the light produced by the lighting system (act **314**) to provide new lighting conditions for the next portion of the object to be identified. While this process can be implemented in numerous ways, in an embodiment the process is executed on a processor (e.g., **104** in FIG. 1) in the machine vision system.

As used herein, the term "LED" should be understood to include light emitting diodes of all types, light emitting polymers, semiconductor dies that produce light in response to current, organic LEDs, electro-luminescent strips, and other such systems. An "LED" may refer to a single light emitting diode having multiple semiconductor dies that are individually controlled. It should also be understood that the term "LED" does not restrict the package type of the LED. The term "LED" includes packaged LEDs, non-packaged LEDs, surface mount LEDs, chip on board LEDs and LEDs of all other configurations. The term "LED" also includes LEDs packaged or associated with material (e.g., a phosphor) wherein the material may convert energy from the LED to a different wavelength.

The term "illuminate" should be understood to refer to the production of a frequency of radiation by an illumination source. The term "color" should be understood to refer to any frequency of radiation within a spectrum; that is, a "color," as used herein, should be understood to encompass frequencies not only of the visible spectrum, but also frequencies in the infrared and ultraviolet areas of the spectrum, and in other areas of the electromagnetic spectrum.

Having described several embodiments of the invention in detail, various modifications and improvements will readily occur to those skilled in the art. Such modifications and improvements are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is provided by way of example only, and is not intended to be limiting. The invention is limited only as defined by the following claims and the equivalents thereto.

What is claimed is:

1. A machine vision system, comprising:

a first processor; and

a lighting system configured to produce and modulate light;

wherein the first processor communicates lighting command signals to the lighting system,

wherein the lighting system further comprises an LED lighting system, and

wherein the LED lighting system further comprises:

a second processor that controls the light output from the LED lighting system in accordance with the lighting command signals received from the first processor.

2. The machine vision system of claim 1, wherein the second processor independently controls the output from at least one first LED and at least one second LED, and wherein the at least one second LED produces a different color than the at least one first LED.

3. The machine vision system of claim 1, wherein the lighting system modulates the light output by the LED lighting system by changing at least one of a hue, saturation and intensity of the light.

4. The machine vision system of claim 1, wherein communication between the first processor and the lighting system is accomplished through at least one of wireless and wired transmission.

5. The machine vision system of claim 1, wherein the LED lighting system further comprises:

- at least one first LED;
- at least one second LED;

wherein the at least one second LED produces a different color light than the at least one first LED; and

wherein the second processor independently controls the at least one first LED and the at least one second LED.

6. The machine vision system of claim 5, wherein the second processor controls the at least one first LED and the at least one second LED with signals that are at least one of pulse width modulated, pulse amplitude modulated, and pulse displacement modulated.

7. The machine vision system of claim 5, wherein the second processor controls at least one of the at least one first LED and the at least one second LED with signals that are analog voltage control signals, analog current control signals, and analog power control signals.

8. The machine vision system of claim 1, wherein the second processor comprises an addressable processor.

9. The machine vision system of claim 8, wherein the lighting command signals comprise addressed lighting command signals.

10. A machine vision system, comprising:
- a first processor; and
 - a lighting system configured to produce and modulate light;

wherein the first processor is configured to communicate lighting command signals to the lighting system, and wherein the lighting system further comprises an addressable processor, and wherein the lighting command signals are directed to the addressable processor.

11. The machine vision system of claim 10, wherein the lighting command signals comprise addressed lighting command signals.

12. The machine vision system of claim 10, wherein the lighting system further comprises an LED lighting system.

13. The machine vision system of claim 12, wherein the lighting system further comprises at least one of a fluorescent light, compact fluorescent light, incandescent light, halogen light, and high intensity discharge light.

14. A method of lighting an object or surface in a machine vision system, comprising acts of:

- providing a machine vision system;
- providing a lighting system capable of producing and modulating light; and

communicating lighting command signals from the machine vision system to the lighting system, wherein the lighting system comprises an LED lighting system,

wherein the LED lighting system further comprises at least one first LED and at least one second LED, wherein the at least one first LED produces a different color than the at least one second LED, and

wherein the lighting system further comprises a processor that independently controls the at least one first LED and the at least one second LED.

15. The method of claim 14, wherein the processor controls the at least one first LED and the at least one second

LED with at least one of pulse width modulated signals, pulse amplitude modulated signals, and pulse displacement modulated signals.

16. The method of claim 14, wherein the processor controls the at least one first LED and the at least one second LED with at least one of analog voltage control signals, analog current control signals, and analog power control signals.

17. The method of claim 14, wherein the processor is an addressable processor.

18. The method of claim 14, wherein the lighting system further comprises at least one of a fluorescent light, compact fluorescent light, incandescent light, halogen light, and high intensity discharge light.

19. The method of claim 14, wherein the machine vision system communicates LED control signals to the LED lighting system.

20. The method of claim 19, wherein the LED control signals are at least one of pulse width modulated signals, pulse amplitude modulated signals, and pulse displacement modulated signals.

21. The method of claim 19, wherein the LED control signals are at least one of analog voltage control signals, analog current control signals, and analog power control signals.

22. The method of claim 14, wherein the LED lighting system is capable of modulating at least one of hue, saturation and intensity of the light produced by the LED lighting system.

23. The method of claim 14, wherein communication between the machine vision system and the lighting system is accomplished through at least one of wired and wireless communication.

24. The method of claim 14, wherein the lighting system comprises a networked lighting system.

25. A method of lighting an object or surface in a machine vision system, comprising acts of:

- providing the machine vision system that includes an optical system for viewing the object;
- providing the object;
- arranging the optical system to view the object;
- arranging a lighting system to irradiate the object, wherein the lighting system is configured to produce and modulate light;

communicating first lighting control commands from the machine vision system to the lighting system; and executing a machine vision function and then having the machine vision system communicate second lighting control commands to the lighting system.

26. The method of claim 25, wherein the machine vision system comprises a color machine vision system.

27. The method of claim 25, wherein the machine vision system comprises a grey scale vision system.

28. The method of claim 25, wherein the lighting system further comprises an LED lighting system.

29. The method of claim 28, wherein the LED lighting system further comprises:

- at least one first LED; and
- at least one second LED that produces a different color than the at least one first LED.

30. The method of claim 29, wherein the LED lighting system further comprises a processor that controls the output from at least one of the at least one first LED and the at least one second LED.

31. The method of claim 30, wherein the processor comprises an addressable processor.

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,624,597 B2
DATED : September 23, 2003
INVENTOR(S) : Kevin J. Dowling et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page.

Item [63], **Related U.S. Application Data**, please replace section [63] with the following:

-- Continuation-in-part of application No. 09/669,121, filed on Sep. 25, 2000, which is a continuation of application No. 09/425,770 filed on Oct. 22, 1999, now Pat. No. 6,150,774, which is a continuation of application No. 08/920,156, filed on Aug. 26, 1997, now Pat. No. 6,016,038. Continuation-in-part of application No. 09/815,418 filed on Mar. 22, 2001, which is a continuation of application No. 09/213,548, filed on Dec. 17, 1998, now Pat. No. 6,166,496. Continuation-in-part of application No. 09/742,017, filed on Dec. 20, 2000, which is a continuation of application No. 09/213,548. Continuation-in-part of application No. 09/626,905, filed on Jul. 27, 2000, which is a continuation of application No. 09/213,659, filed on Dec. 17, 1998, now Pat. No. 6,211,626. Continuation-in-part of application No. 09/333,739, filed on Jun. 15, 1999, and a continuation-in-part of application No. 09/215,624, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,607, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,581, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,540, filed on Dec. 17, 1998, and a continuation-in-part of application No. 09/213,189, filed on Dec. 17, 1998. --

Item [56], **References Cited**, U.S. PATENT DOCUMENTS, please add
-- 6,273,338 B1 8/2001 White -- after "6,250,774 6/2001 Begemann et al."

Signed and Sealed this

Tenth Day of February, 2004



JON W. DUDAS
Acting Director of the United States Patent and Trademark Office