US006718049B2

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

(10) **Patent No.: US 6,718,049 B2**
(45) **Date of Patent: Apr. 6, 2004**

(54) **NEAR-INFRARED DISGUISE DETECTION**

(75) Inventors: **Ioannis Pavlidis**, Houston, TX (US); **Peter F. Symosek**, Shoreview, MN (US); **Bernard S. Fritz**, Eagan, MN (US)

(73) Assignee: **Honeywell International Inc.**, Morristown, NJ (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.: **10/308,465**

(22) Filed: **Dec. 3, 2002**

(65) **Prior Publication Data**

US 2003/0169901 A1 Sep. 11, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/732,236, filed on Dec. 7, 2000, which is a continuation-in-part of application No. 09/389,925, filed on Sep. 3, 1999, now Pat. No. 6,370,260.
(60) Provisional application No. 60/210,280, filed on Jun. 8, 2000.

(51) **Int. Cl.**[7] **G06K 9/00**
(52) **U.S. Cl.** **382/115**; 348/164; 348/169
(58) **Field of Search** 382/103, 107, 382/115, 118, 218, 209, 210, 211, 212; 340/5.53, 5.83, 426.26, 545.3; 348/169, 584; 250/339, 339.1; 356/51, 388, 448; 359/350, 356

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,057,352 A		11/1977	Babb	
4,500,784 A	*	2/1985	Hacskaylo	250/339.11
4,520,504 A	*	5/1985	Walker et al.	382/100
4,733,081 A		3/1988	Mizukami	
5,013,917 A		5/1991	Ulich	
5,221,919 A		6/1993	Hermans	
5,293,427 A	*	3/1994	Ueno et al.	382/103
5,703,367 A		12/1997	Hashimoto et al.	
5,792,050 A	*	8/1998	Alam et al.	600/310
5,801,763 A		9/1998	Suzuki	
5,866,887 A	*	2/1999	Hashimoto et al.	235/98 R
5,900,942 A		5/1999	Spiering	
5,940,139 A	*	8/1999	Smoot	348/584
6,002,505 A		12/1999	Kraenert et al.	
6,178,259 B1		1/2001	Harris	
6,353,764 B1	*	3/2002	Imagawa et al.	700/1
6,370,260 B1		4/2002	Pavlidis et al.	
6,498,564 B2	*	12/2002	Oda	340/567

FOREIGN PATENT DOCUMENTS

EP	0 990 416 A1	4/2000
WO	97/21188	6/1997

OTHER PUBLICATIONS

Ballard, "Generalizing the Hough Transform to Detect Arbitrary Shapes, "Pattern Recognition, vol. 13, No. 2, pp. 111–122, 1981.

Fendt et al., "The Neuroanatomical and Neurochemical Basis of Conditioned Fer," Neurosci Biobehav Rev. 23(5):743–60 (May 1999).

Huang et al., "Face Detection and Precise Eyes Location," in Proceedings 15th International Conference on Pattern Recognition, 2000, vol. 4, pp. 722–727.

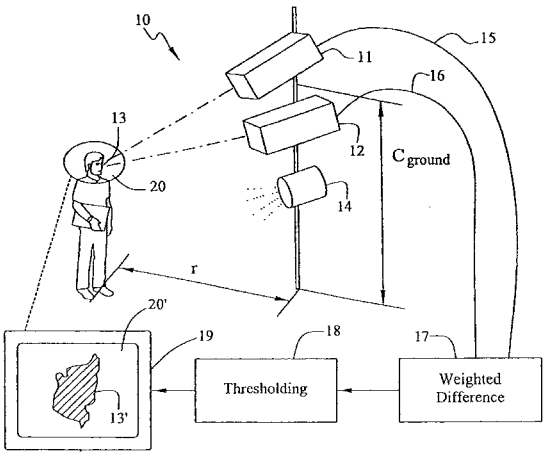
(List continued on next page.)

Primary Examiner—Jayanti K. Patel
Assistant Examiner—Abolfazl Tabatabai
(74) *Attorney, Agent, or Firm*—Kris T. Fredrick

(57) **ABSTRACT**

Detection of a person disguised with one or more artificial materials includes detecting reflection from at least one portion of a head of a human body in at least a portion of an upper band of the near infrared spectrum. The presence of an artificial material associated with the head of the human body is determined based on the detected reflection.

28 Claims, 12 Drawing Sheets



OTHER PUBLICATIONS

Jacquez et al., "The Spectral Reflectance of Human Skin in the Region 0.7–2.6 μm," Technical Report, 189, Army Medical Research Laboratory, Fort Knox (Apr. 1955).

Jeon et al., "Rotation Invariant Face Detection Using a Model–Based Clustering Algorithm," in Proceedings 2000 IEEE International Conference on Multimedia and Expo, 2000, vol. 2, pp. 1149–1152.

Jordan et al., "Hierarchical Mixtures of Experts and the EM Algorithm," Neural Computation, pp. 181–214 (1994).

Kawato et al., "Two Step Approach for Real–Time Eye Tracking with a New Filtering Technique," in Proceedings 2000 IEEE International Conference on Systems, Man, and Cybernetics, 2000, vol. 2, pp. 1366–1371.

Kim et al., "Face Detection Using Multi–Modal Information" in Proceedings Fourth IEEE International Conference on Automatic Face and Gesture Recognition, 2000, pp. 14–19.

Levine et al., "The Energy Expended in Chewing Gum," New England Journal of Medicine, 341(27):2100 (Dec. 1999).

Li et al., "Multi–View Face Detection Using Support Vector Machines and Eigenspace Modeling," in Proceedings Fourth International Conference on Knowledge–Based Intelligent Engineering Systems & Allied Technologies, 2000, vol. 1, pp. 241–244.

Lv et al., "A Novel Algorithm for Rotated Human Face Detection" in Proceedings IEEE Conference on Computer Vision and Pattern Recognition, 2000, vol. 1, pp. 760–765.

Mendez, The Master of Disguise, William Morrow and Co., New York, NY: cover page, title page, copyright page and table of contents only; 4 pgs. (1999).

Moghaddam et al., "Probabilistic Visual Learning for Object Recognition," IEEE Trans. Pattern Analysis and Machine Intelligence, 19(7):696–710 (Jul. 1997).

Morimoto et al., "Real–Time Multiple Face Detection Using Active Illumination," in Proceedings Fourth IEEE International Conference on Automatic Face and Gesture Recognition, 2000. pp. 8–13.

Otsu, "A Threshold Selection Method from Gray–Level Histograms," IEEE Trans. Systems, Man and Cybernetics, 9:(1)62–65 (Jan. 1979).

Pavlidis et al., "Automatic Passenger Counting in the High Occupancy Vehicle (HOV) Lanes", Proceedings 1999 Annual Meeting of the Intelligent Transportation Society of America, Washington, D.C. (Apr. 19–22, 1999).

Pavlidis et al., "A Near–Infrared Fusion Scheme for Automatic Detection of Vehicle Passengers," Proceedings 1999 IEEE Workshop on Computer Vision Beyond the Visible Spectrum: Methods and Applications, 41–48, Fort Collins, CO (Jun. 22, 1999).

Pavlidis et al., "A Vehicle Occupant Counting System Based on Near–Infrared Phenomenology and Fuzzy Neural Classification,"IEEE Transactions on Intelligent Transportation Systems, vol. 1, No. 2, pp. 72–85, Jun. 2000.

Pavlidis et al., "The Imaging Issue in an Automatic Face/Disguise Detection System," in Proceedings IEEE Workshop on Computer Vision beyond the Visible Spectrum: Methods and Applications, 2000. pp. 15–24.

Penev et al., "Local Feature Analysis: A General Statistical Theory for Object Representation," Network: Computation in Neural Systems, 7(3):477–500 (Aug. 1996).

Pentland et al., "Face Recognition for Smart Environments," IEEE Computer, 33(2):50–55 (Feb. 2000).

Phillips et al., The FERET Database and Evaluation Procedure for Face–Recognition Algorithms, Image and Vision Computing, 16(5):295–306 (Apr. 1998).

Prokoski, "Disguise Detection and Identification Using Infrared Imagery," Proceedings of SPIE, Optics, and Images in Law Enforcement II, 339:27–31, A.S. Hect, ed., Arlington, VA (May 1982).

Prokoski et al., "Identification of Individuals by Means of Facial Thermograph" Proceedings of the International Carnahan Conference on Security Technology: Crime Countermeasures. Atlanta, Oct. 14–16, 1992, NY, IEEE US, Oct. 14, 1992 pp. 120–125, XP000357473, p. 121, Right–Hand Column, Line 4, p. 122, Left–Hand Column, Last Paragraph: Table 2.

Rowley et al., "Neural Network–Based Face Detection," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 20, No. 1 pp. 23–38, Jan. 1998.

Sabins, Remote Sensing, Principles and Interpretation, W.H. Freeman and Company, New York, NY; cover page, title page, copyright page and table of contents only; 7 pgs. (1997, 3rd ed.).

Sliney, "Laser and LED Eye Hazards: Safety Standards," Optics and Photonics News, pp. 32–(Sep. 1997).

Visionics Corporation, "Face Detection Constantly Searches for Faces in a Datastream", Jersey City, NJ; retrieved from the Internet on Jun. 25, 2001.

Wilder et al., "Comparison of Visible and Infra–Red Imagery for Face Recognition," Proceedings Second IEEE International Conference on Automatic Face and Gesture Recognition, 1996, pp. 182–187.

Wiskott et al., "Face Recognition by Elastic Bunch Graph Matching," IEEE Trans. Pattern Analysis and Machine Intelligence, 19(7):775–779 (Jul. 1997).

Zhu et al., "Region Competition: Unifying Snakes, Region Growing, and Bayes/MDL for Multiband Image Segmentation," IEEE Transactions on Image Analysis and Machine Intelligence 18(9):884–900 (Sep. 1996).

Zhu et al., "Fast Face Detection Using Subspace Discriminant Wavlet Features," in Proceedings IEEE Conference on Computer Vision and Pattern Recognition, 2000, vol. 1, pp. 636–641.

* cited by examiner

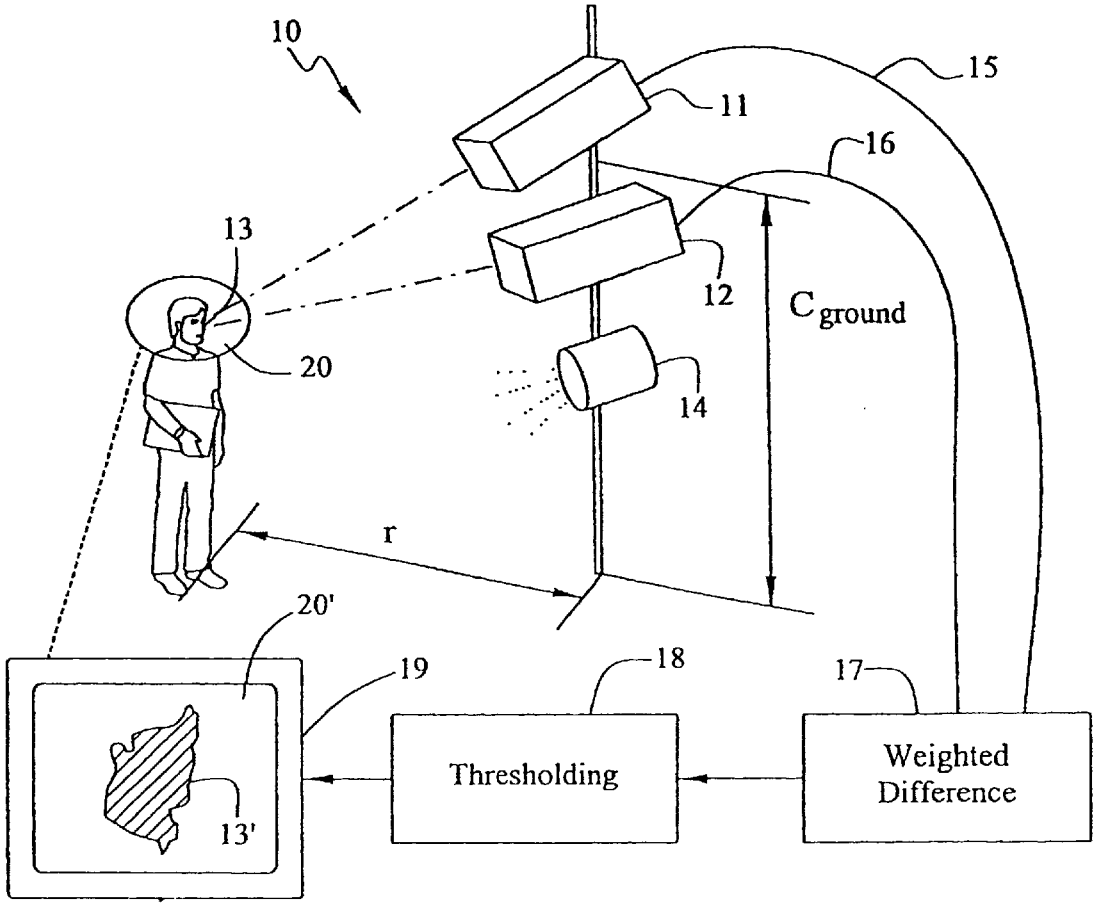

10
11
12
13
14
15
16
20
r
C_{ground}
20'
19
18
17
Thresholding
Weighted Difference
13'

Fig. 1

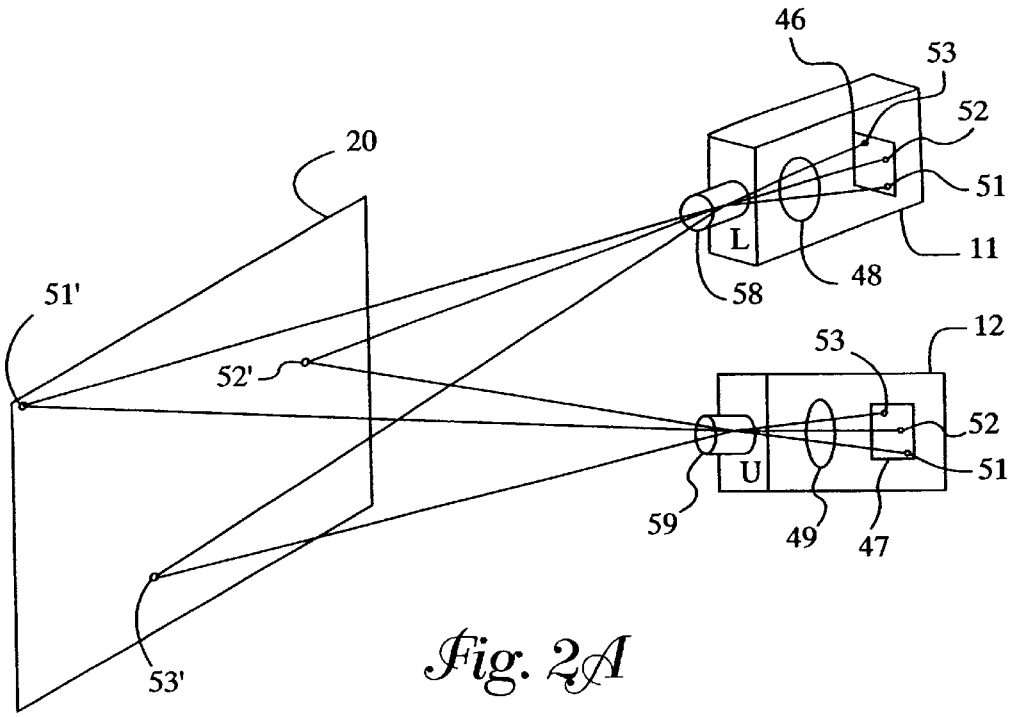

46
53
52
20
51
L
11
48
58
51'
52'
53
12
52
U
51
59
49
47
53'

Fig. 2A

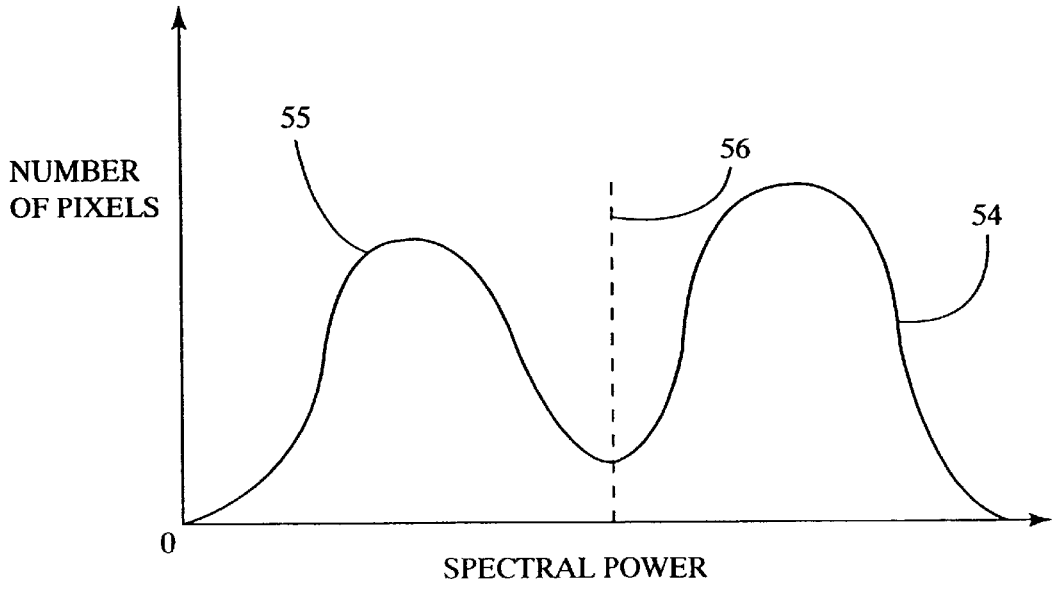

NUMBER
OF PIXELS
55
56
54
0
SPECTRAL POWER

Fig. 3

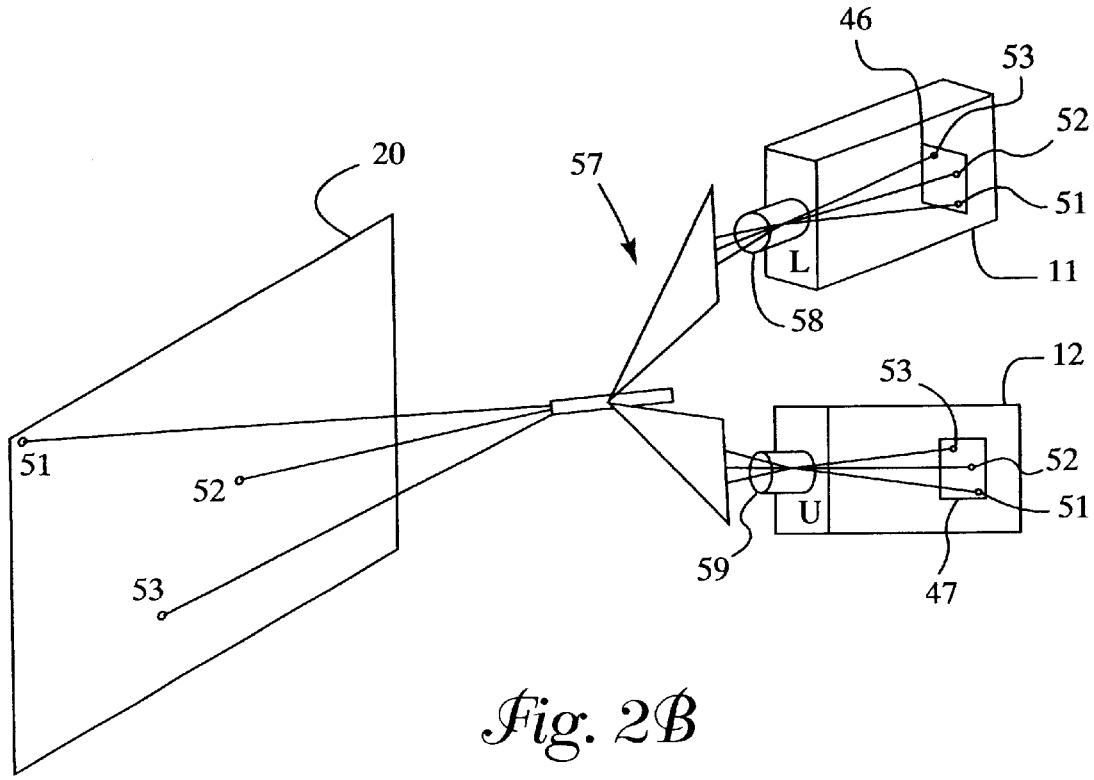


Fig. 2B

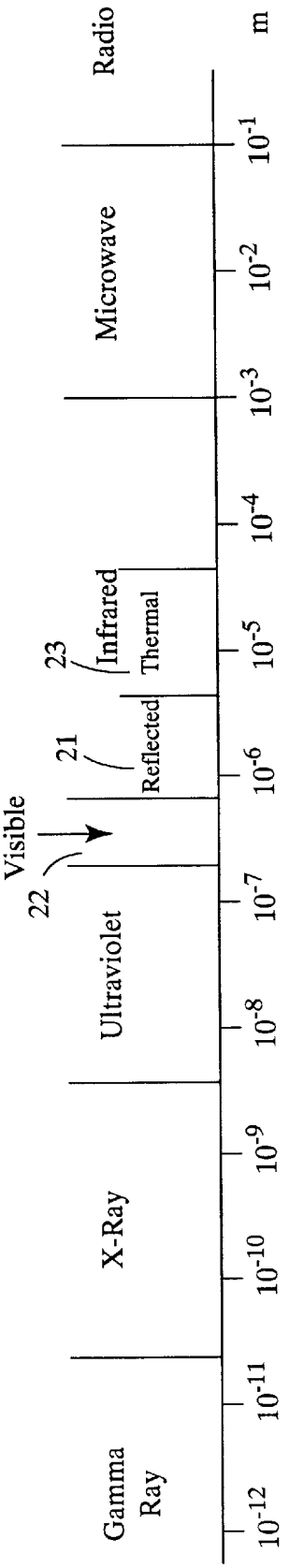

Gamma Ray
X-Ray
Ultraviolet
Visible
Reflected
Infrared
Thermal
Microwave
Radio
22
21
23
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
m
Wavelength

Fig. 4

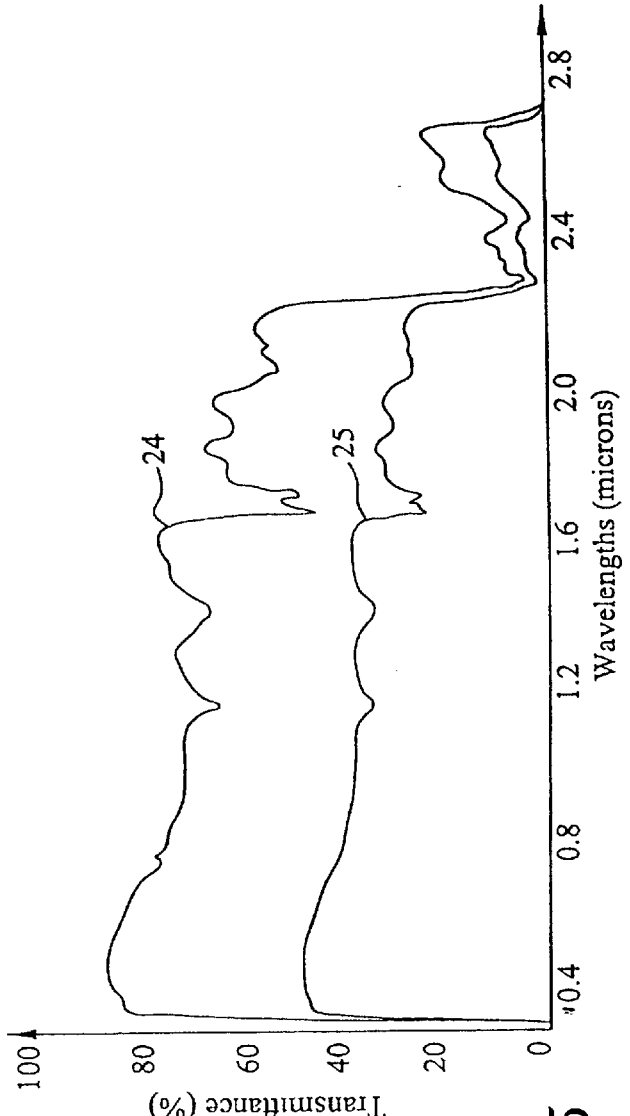

100
80
60
40
20
0
Transmittance (%)
24
25
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Wavelengths (microns)

Fig. 5

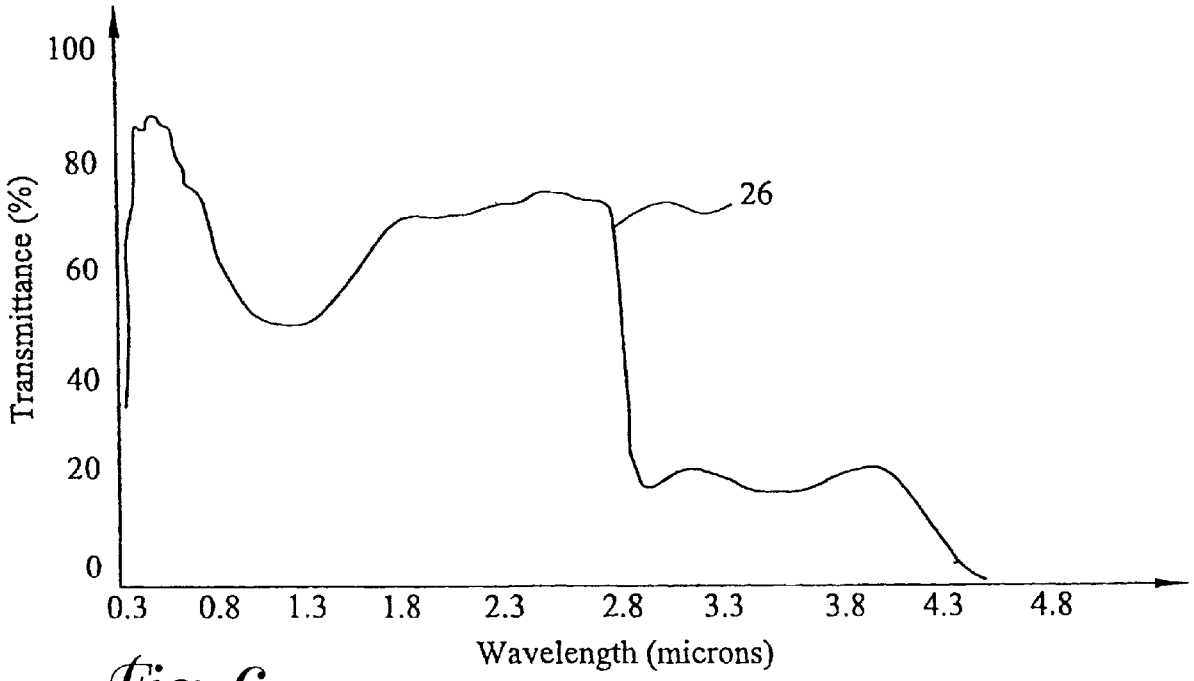

100
80
60
40
20
0
Transmittance (%)
26
0.3
0.8
1.3
1.8
2.3
2.8
3.3
3.8
4.3
4.8
Wavelength (microns)

Fig. 6

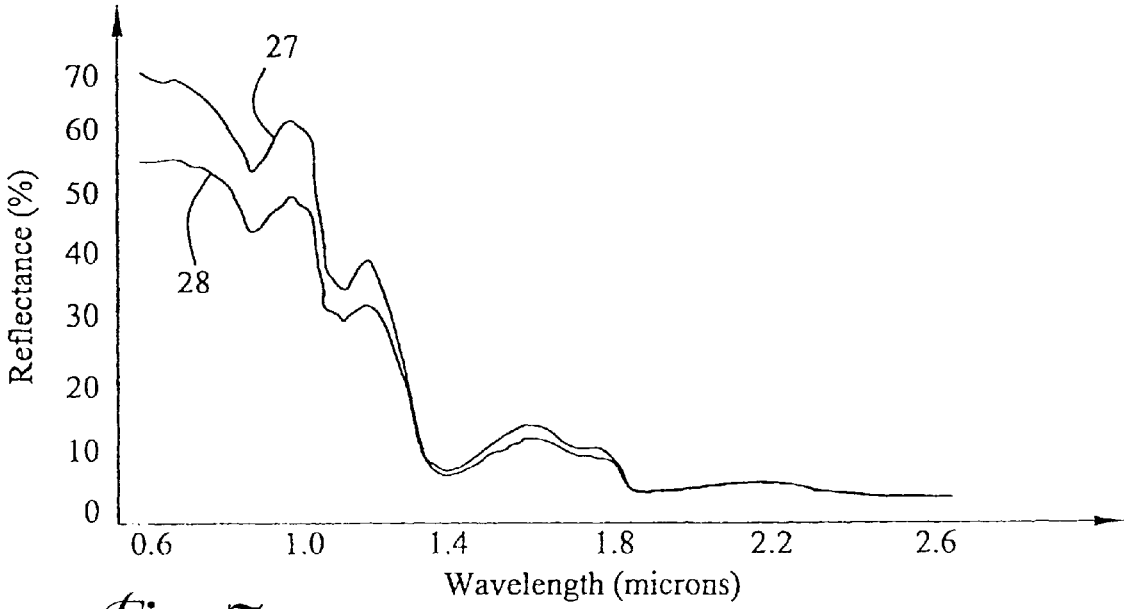

70
60
50
40
30
20
10
0
Reflectance (%)
27
28
0.6
1.0
1.4
1.8
2.2
2.6
Wavelength (microns)

Fig. 7

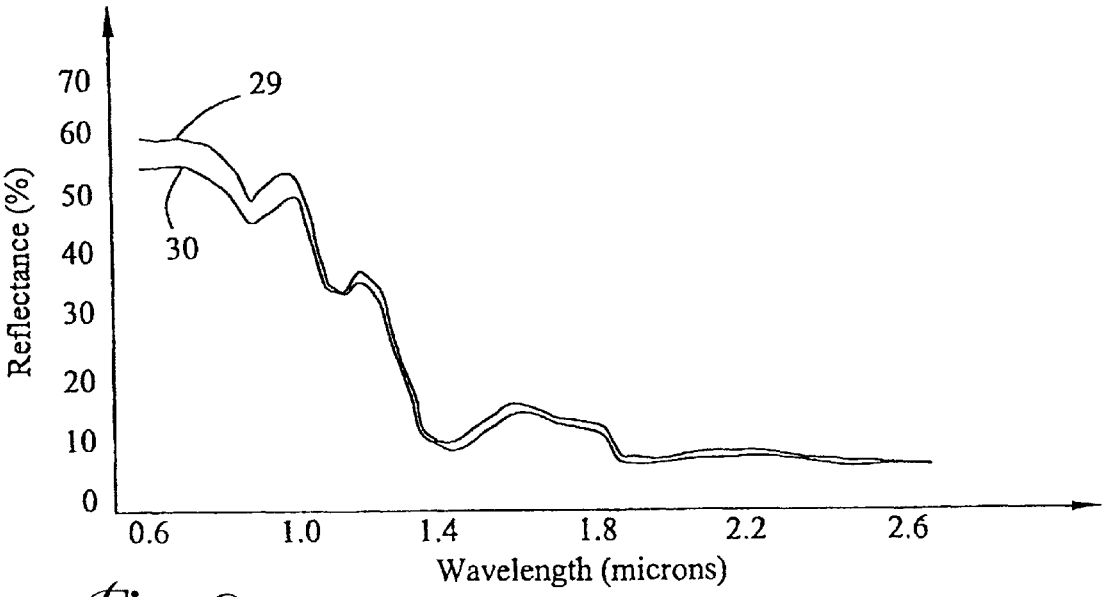

70
60
50
40
30
20
10
0
Reflectance (%)
29
30
0.6
1.0
1.4
1.8
2.2
2.6
Wavelength (microns)

Fig. 8

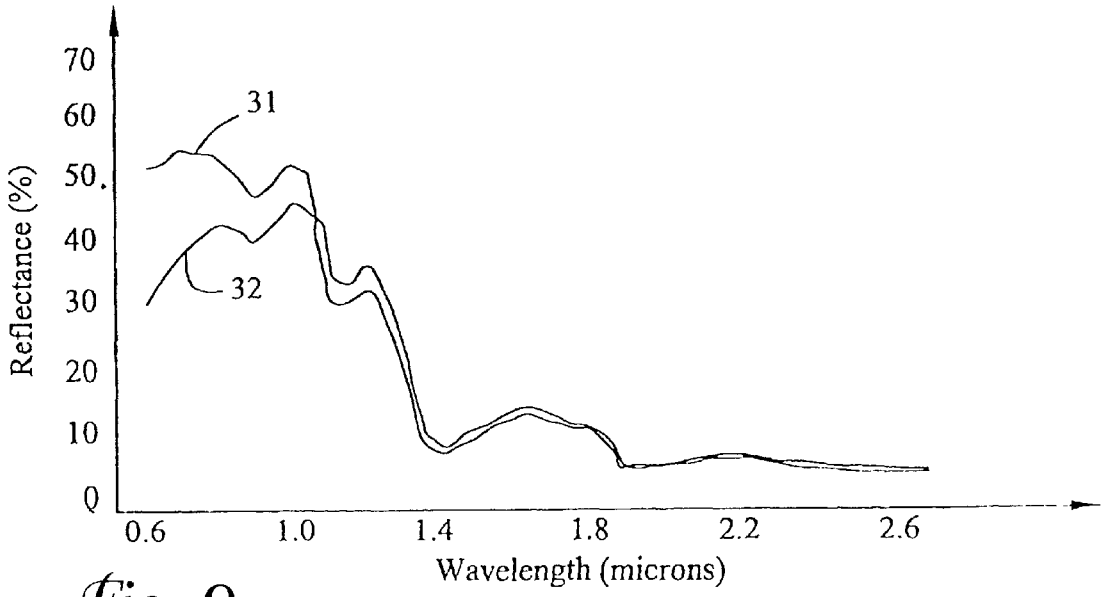

70
60
50
40
30
20
10
0
Reflectance (%)
31
32
0.6
1.0
1.4
1.8
2.2
2.6
Wavelength (microns)

Fig. 9

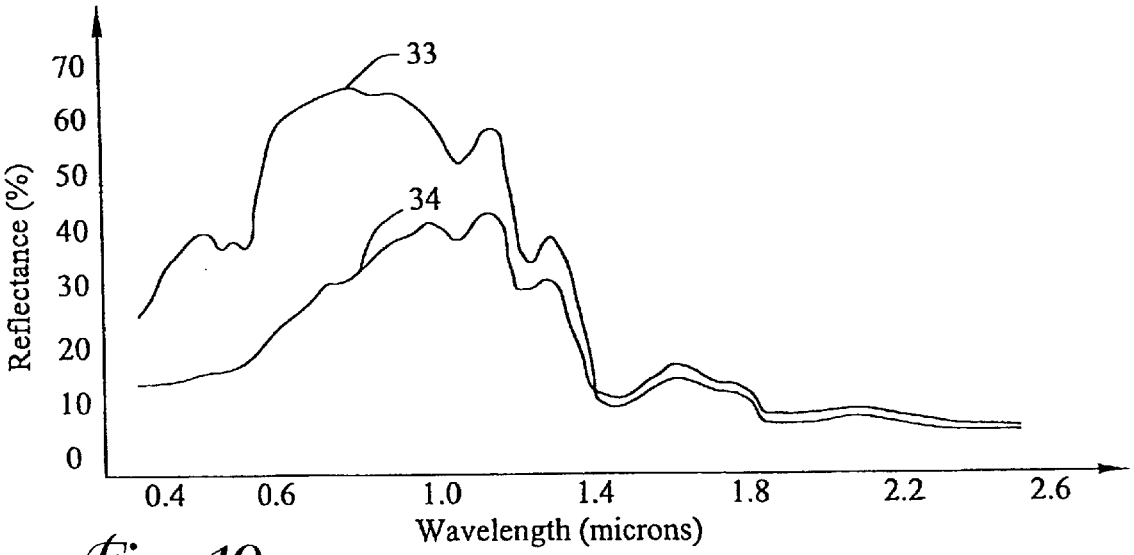

33
34
70
60
50
40
30
20
10
0
Reflectance (%)
0.4
0.6
1.0
1.4
1.8
2.2
2.6
Wavelength (microns)

Fig. 10

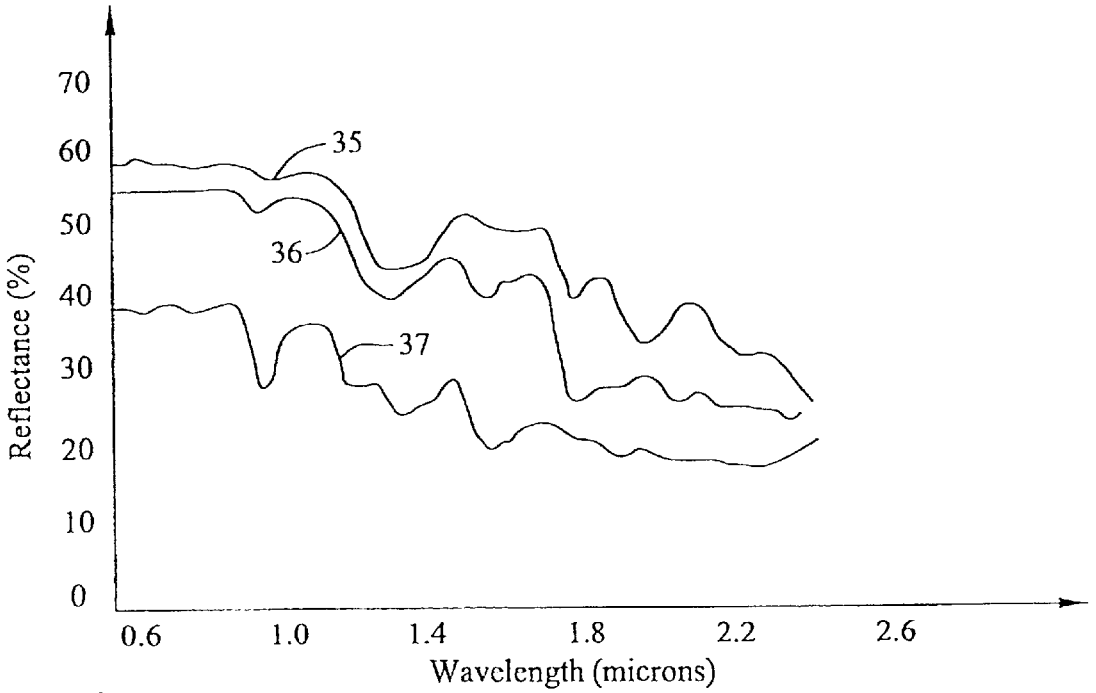

35
36
37
70
60
50
40
30
20
10
0
Reflectance (%)
0.6
1.0
1.4
1.8
2.2
2.6
Wavelength (microns)

Fig. 11

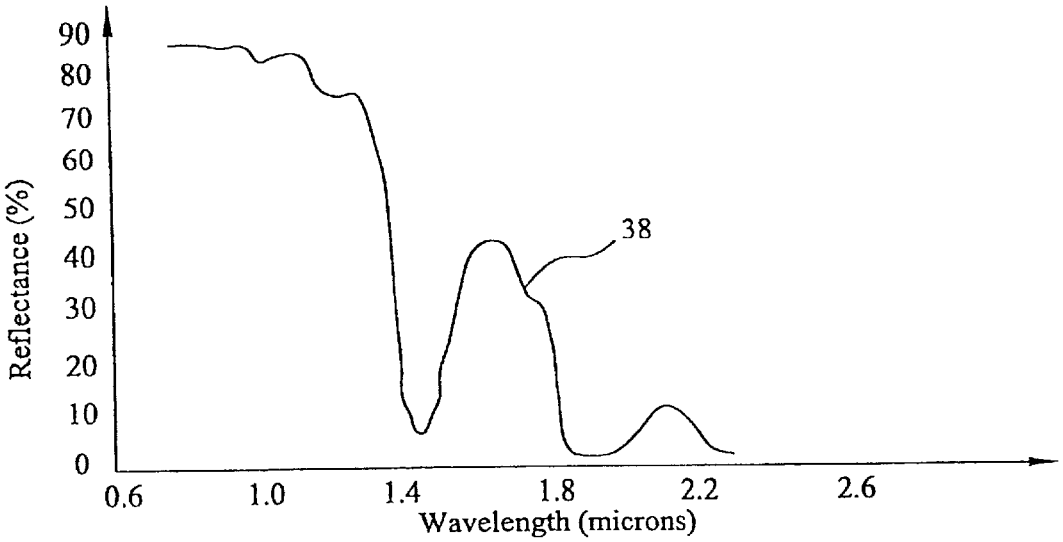

90
80
70
60
50
40
30
20
10
0
Reflectance (%)
38
0.6
1.0
1.4
1.8
2.2
2.6
Wavelength (microns)

Fig. 12

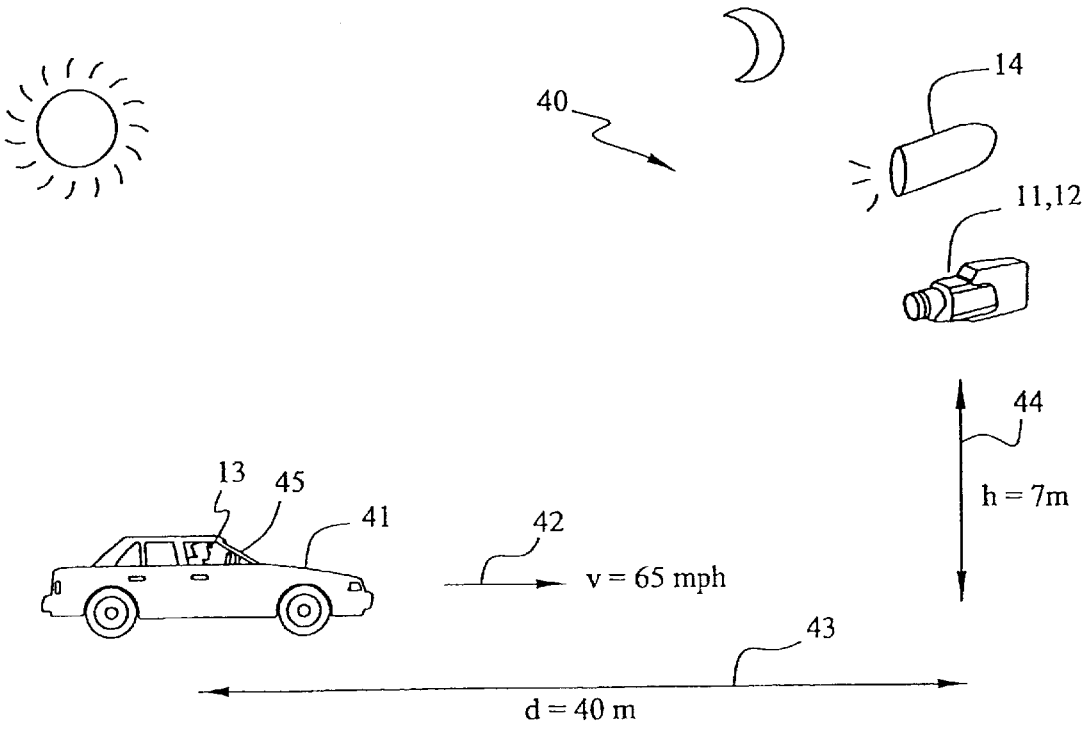

40
14
11,12
44
h = 7m
13
45
41
42
v = 65 mph
43
d = 40 m

Fig. 13

Fig. 14A

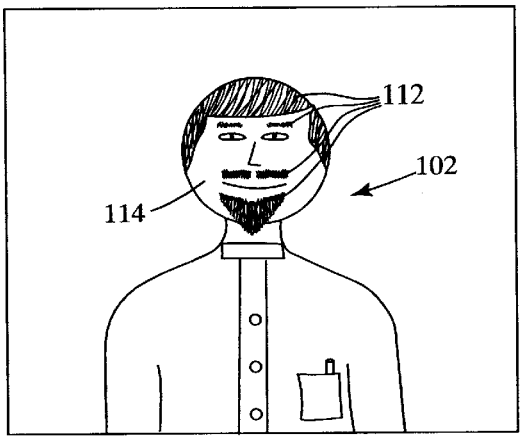


Fig. 14B

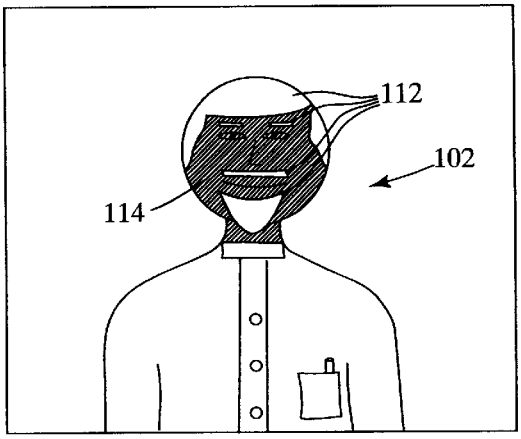


Fig. 15A

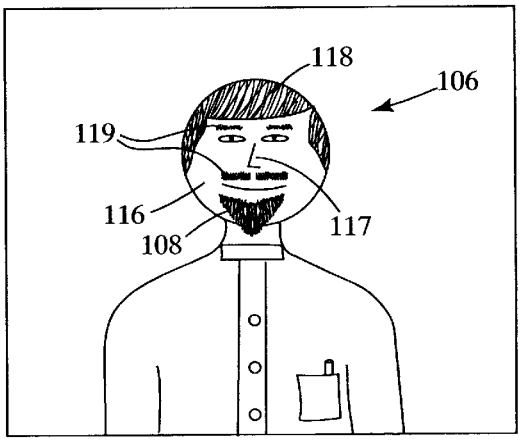
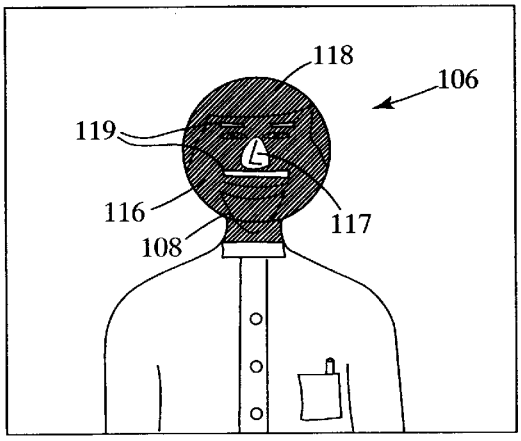


Fig. 15B



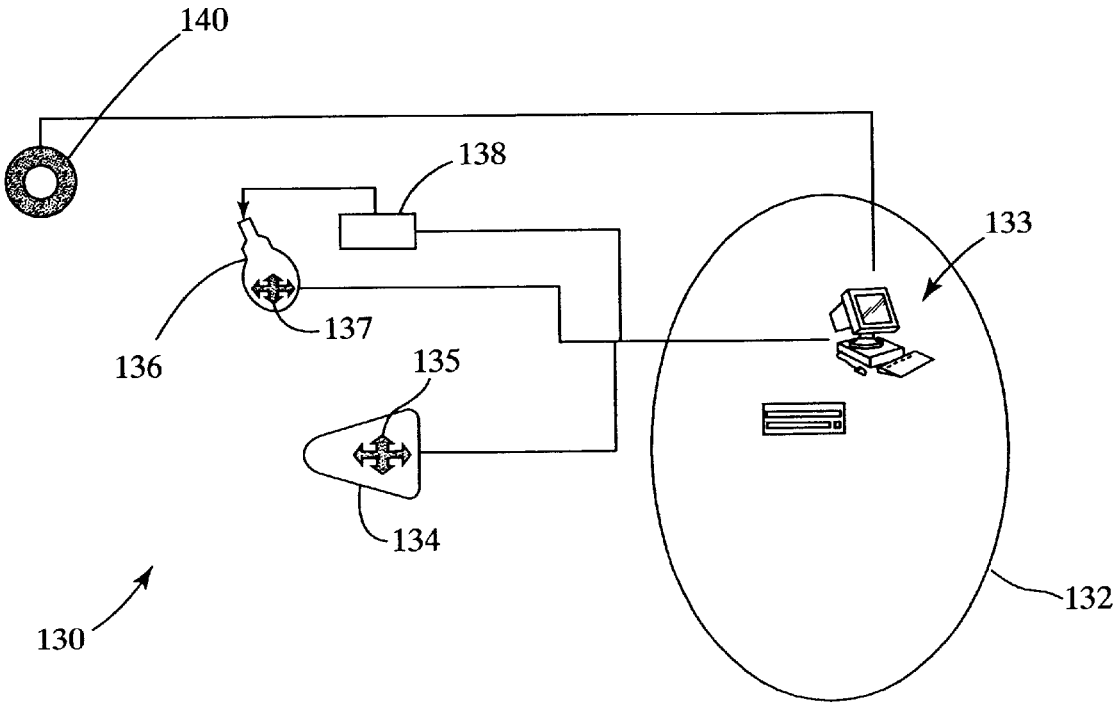


Fig. 16

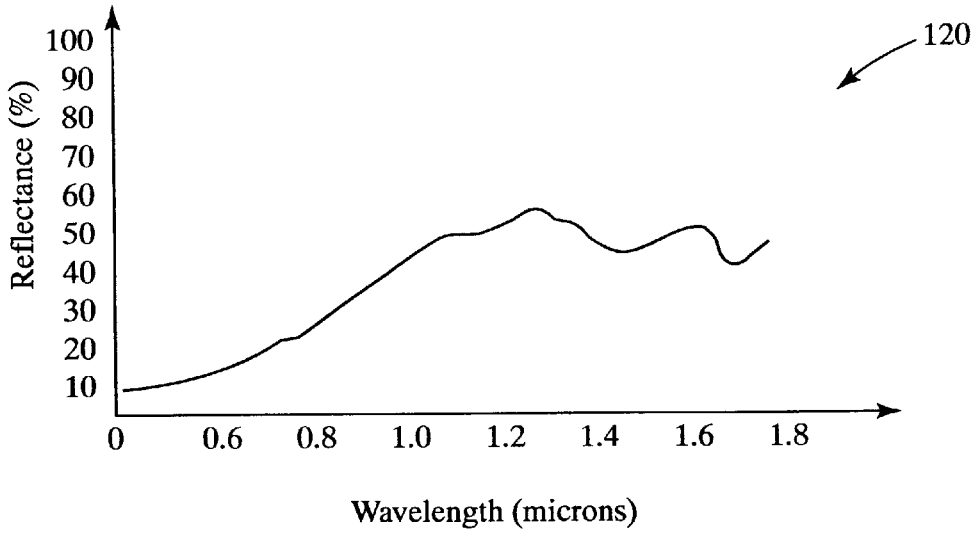

120
Reflectance (%)
100
90
80
70
60
50
40
30
20
10
0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Wavelength (microns)

Fig. 17

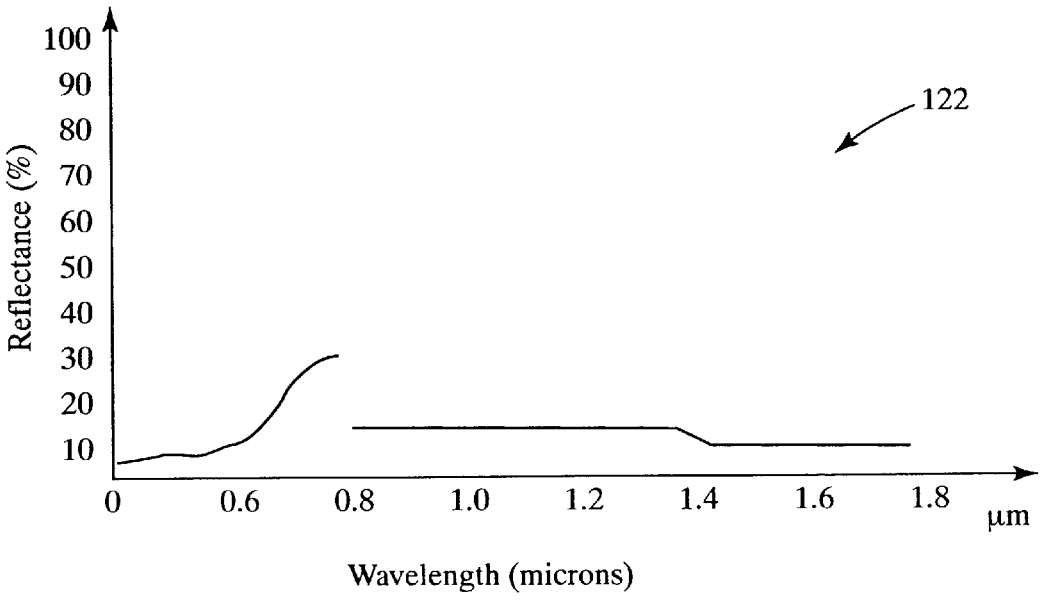

122
Reflectance (%)
100
90
80
70
60
50
40
30
20
10
0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
μm
Wavelength (microns)

Fig. 18

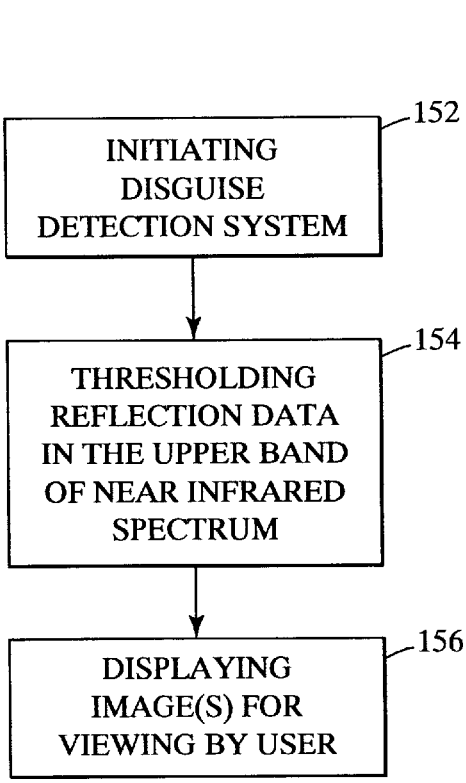

150
INITIATING DISGUISE DETECTION SYSTEM
152
THRESHOLDING REFLECTION DATA IN THE UPPER BAND OF NEAR INFRARED SPECTRUM
154
DISPLAYING IMAGE(S) FOR VIEWING BY USER
156

Fig. 19

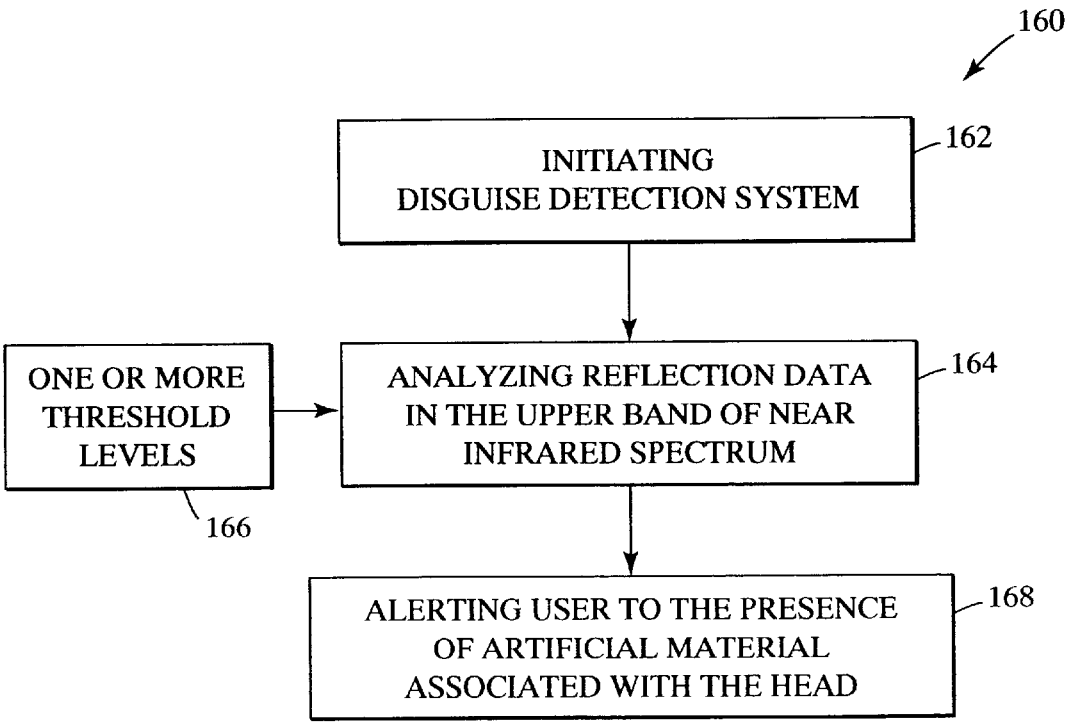

160
INITIATING DISGUISE DETECTION SYSTEM
162
ONE OR MORE THRESHOLD LEVELS
166
ANALYZING REFLECTION DATA IN THE UPPER BAND OF NEAR INFRARED SPECTRUM
164
ALERTING USER TO THE PRESENCE OF ARTIFICIAL MATERIAL ASSOCIATED WITH THE HEAD
168

Fig. 20

NEAR-INFRARED DISGUISE DETECTION

This is a continuation of application Ser. No. 09/732,236, filed Dec. 7, 2000, (pending), which is a continuation-in-part of Ser. No. 09/389,925, filed Sep. 3, 1999, and which claims the benefit of Ser. No. 60/210,280, filed Jun. 8, 2000, which are all incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention pertains to detection systems and methods. More particularly, the present invention pertains to detection systems and methods using the near-infrared spectrum for the detection of, for example, disguised persons.

In certain situations, disguise detection is of paramount importance. For example, in high-end security applications, e.g., surveillance of an embassy perimeter where there is a need to know if disguised terrorists are staking out a facility, disguise detection is required. Sophisticated systems for early detection and identification of individuals at a distance need to be developed and implemented for future security systems.

Sophisticated terrorists use both natural (e.g., darkness, weather, blending into the background) and man-made (e.g., heavy make-up, artificial face parts, add-on hair, etc.) deception and disguise techniques to avoid identification. Currently, systems that can determine whether an individual is wearing a facial disguise are lacking. Therefore, face identification processes and systems that have the capability to identify a particular human face cannot even be initiated, or even if such processes are initiated, the processes do not know of the possible disguise being used by the individual. Therefore, the face identification processes are easily rendered ineffective. As such, the mere detection of a disguised individual on the perimeter is highly valuable to security forces.

One article entitled "Disguise detection and identification using infrared imagery," by F. J. Prokoski, *Proceedings of SPIE, Optics, and Images in Law Enforcement II*, A. S. Hecht, Ed., Arlington, pp. 27–31, Virginia, May 1982, describes a disguise detection system that uses facial thermograms in the thermal infrared spectrum for the detection of disguises and in positive identification of known individuals. However, thermal infrared radiation does not transmit effectively through glass, e.g., so as to allow for detection of disguises within vehicles.

Other portions of the spectrum are also ineffective for use in disguise detection. For example, even though the visible spectrum has been used in imaging and detecting individuals, such visible spectrum systems or methods are not effective for disguise detection. Disguises cannot be detected in the visible band because by definition such disguises are meant to cheat the human eye and the other sensors that operate in the same wavelength. In other words, in the visible spectrum, artificial materials disguising an individual are not detectable.

Further, for example, the lower portion of the electromagnetic spectrum consists of gamma rays, x-rays, and radiation in the ultra-violet range. Radiation of such wavelengths is harmful. Thus, such radiation that is typically useful in a controlled manner, e.g., for medical applications, cannot generally be used for disguise detection.

At the far end of the electromagnetic spectrum, there is microwave and radio radiation. This range of the spectrum has recently started to be exploited for imaging purposes. Sensors operate in an active or in passive mode. The major advantage of such longer wavelengths is that they can penetrate clouds, fog, and rain for producing weather independent imaging results. However, the technology for such wavelengths is new and prohibitively expensive. Also, the sensors available for detection in this range of radiation are extremely large and have very low resolution.

Related efforts by others, for example, in the field of detecting occupants in vehicles, such as for gathering statistics in high occupancy vehicle lanes which can be used for road construction planning, have involved the use of a near-infrared camera (i.e., in the range of 0.55 to 0.90 micron) and a near-infrared illumination source in the same range of wavelengths. One reason for using near-infrared sensing is the ability to use non-distracting illumination at night. Illumination at nighttime enhances the quality of the image. However, it appears that this choice of range of wavelengths is not appropriate because of its close proximity to the visible spectrum. Experiments have shown that the human eye has some sensitivity to this range of near-infrared wavelengths, however small. Another reason for this approach, was to bypass problems caused by solar illumination during daytime, such as glare from glass of vehicles. Nevertheless, particularly in this range of the spectrum (i.e., 0.55 to 0.9 micron) solar illumination is still substantial and the associated glare can be reduced only through the use of polarizing filters.

Further, in more general terms, related art projects that involve imaging usually adopt the use of visible spectrum cameras which as described above, are ineffective in disguise detection. One strong point of the visible spectrum is that the relevant imaging sensors are very advanced and at the same time very economical. Visible spectrum cameras have a particular advantage in terms of speed, which is an important consideration, for example, in detecting occupants in vehicles, where vehicles are moving at rates of speed of 65 mph. These cameras can also have very high resolution, resulting in very clear images under various conditions. However, unfortunately, in addition to not detecting disguised individuals, there are other serious problems with the visible spectrum approach. For instance, some vehicles have heavily tinted window glass to reduce glare from solar illumination. This glass is nearly opaque to visible spectrum cameras. Also, visible spectrum cameras do not have operational capability during nighttime.

Visible spectrum or very near infrared detection of people in vehicles has not been very successful under most conditions. The glare and other problems caused by solar illumination, such as through vehicle windows, has prevented effective detection of vehicle occupants. Also, environmental conditions like weather obscure detection. People appear to have darker or lighter faces, depending on the characteristics of the people being detected, and on the incident angle and intensity of deliberate or incidental illumination.

SUMMARY OF THE INVENTION

Various embodiments of the present invention provide solutions to one or more problems existing with respect to detection systems and methods, and in particular disguise detection systems and methods. Such embodiments may provide one or more of the following advantages. For example, disguised faces may be detected within vehicles through window glass thereof. Further, the present invention provides a simple thresholding system that can deliver excellent disguise detection results. In addition, the existence of specific materials used for disguise purposes may be identified.

The present invention capitalizes on the unique and universal properties of the natural human skin and/or natural human hair in the upper band of the near-infrared spectrum. Some embodiments of the methods according to the present invention include one or more of the following: detecting reflection from at least one portion of a head of a human body in at least a portion of an upper band of the near-infrared spectrum (e.g., at least a portion within the range of 1.4 μm and greater in the upper band of the near-infrared spectrum); determining the presence of an artificial material associated with the head of the human body based on the detected reflection; detecting reflection from at least a skin portion of the head of the human body; detecting reflection from at least a hair portion of the head of the human body; determining the presence of an artificial material associated with the head of the human body by displaying to a user a representation of the detected reflection; determining the presence of an artificial material associated with the head by generating data representative of the detected reflection and comparing the data to at least one threshold reference reflection level; identifying one or more artificial materials associated with the head; basing the threshold reference reflection level(s) on a level of reflection of natural skin of the human body, the level of reflection of natural hair of the human body, or the level of reflection of one or more artificial materials; using an illumination source matched to the upper band of the near-infrared spectrum detected to illuminate the head of the human body; controlling the illumination source based on a detected illumination level to maintain the desired illumination level on the head of the human body.

Some embodiments of a disguised person detection system include one or more of the following features: a detector apparatus operable to detect reflection from at least a portion of the head of the human body in at least a portion of an upper band of the near-infrared spectrum; an indication apparatus operable to provide a user with information as to the presence of an artificial material associated with the head of the human body based on the detected reflection (e.g., wherein the indication apparatus comprises a display operable to provide a representation of the detected reflection and/or wherein the indication apparatus may comprise circuitry operable to compare information representative of the deflected reflection to one or more threshold reference reflection levels, wherein the threshold reference reflection levels may be based on a level of reflection of one or more artificial materials, the natural skin of the human body, the natural hair of the human body, etc.); an illumination source matched to the at least a portion of the upper band of the near-infrared spectrum and positioned to illuminate at least a portion of the head of the human body; a detector operable to detect an illumination level proximate the head so as to provide information to circuitry operable to control the illumination source based on the detected illumination level such that a desired illumination level can be maintained.

Further, in other embodiments of the present invention, a detection method may include detecting reflection from a scene in at least a portion of at least one band of the near-infrared spectrum, and thereafter, determining the presence of a head of the human body in the scene. The features of the disguise detection methods and/or system described above may then be used to determine the presence of an artificial material associated with the detected head.

The above summary of the present invention is not intended to describe each embodiment or every implementation of the present invention. Advantages, together with a more complete understanding of the invention, will become apparent and appreciated by referring to the following detailed description and claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE EMBODIMENTS

FIG. **1** shows a near-infrared fusion system for detecting humans.

FIG. **2**A illustrates a co-registration scheme for two cameras.

FIG. **2**B shows an alternate embodiment for co-registration of the cameras.

FIG. **3** is a histogram of the number of pixels versus spectral power for an image frame.

FIG. **4** is a graph of the electromagnetic (EM) spectrum.

FIG. **5** reveals the infrared transmittance characteristics for an automobile windshield.

FIG. **6** reveals the infrared transmittance characteristics for an automobile side window.

FIG. **7** is a graph showing the percentage of reflectance for Caucasian males of light and dark complexions.

FIG. **8** is a graph showing the percentage of reflectance for Asian males of light and dark complexions.

FIG. **9** is a graph showing the percentage of reflectance for black males of light and dark complexions.

FIG. **10** is a graph showing a comparison of reflectance for light and dark skin.

FIG. **11** is a graph of reflectance for cotton, wood and polyamide.

FIG. **12** is a graph of reflectance for distilled water.

FIG. **13** shows a layout for determining the speed characteristics of a human detection system.

FIGS. **14**A–B shows the appearance of an undisguised individual in the visible spectrum and in the upper band of the near-infrared spectrum, respectively.

FIGS. **15**A–B show the appearance of a disguised individual in the visible spectrum and in the upper band of the near-infrared spectrum, respectively.

FIG. **16** shows one illustrative embodiment of a disguise detection system according to the present invention.

FIG. **17** is a graph of reflectance for natural human hair.

FIG. **18** is a graph of reflectance for a true human hair toupee.

FIG. **19** is an illustrative embodiment of one disguise detection method according to the present invention.

FIG. **20** is yet another alternate embodiment of a disguise detection method according to the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

FIG. **1** shows a basic layout of a near-infrared fusion system **10** for detecting humans. It is a dual-band imaging system. Two co-registered cameras **11** and **12** sense the image of, for instance, a face **13** of a human being. Camera **11** has a spectral sensitivity of 0.8 to 1.4 microns. Camera **12** has a spectral sensitivity of 1.4 to 2.2 microns. Slightly shorter or longer ranges can also yield acceptable detection results. The 1.4 micron threshold point between the two bands of spectral sensitivity is a preferable demarcation point for the dual-band system **10**, but may be another value as appropriate. Each of the camera sensitivity band ranges can cross somewhat the 1.4 micron wavelength without diminishing the human detecting ability of system **10**.

The quality of the imaging signals from cameras **11** and **12** remain high even during overcast days and at nighttime, because the scene being scanned by cameras **11** and **12**, can be illuminated with an eye-safe near-infrared illuminator **14**. Since the eye is not sensitive to the near-infrared spectrum, system **10** can remain stealthy all of the time, whether in a detection mode or not. Ideally, the camera at the lower band range (0.8 to 1.4 microns) should be an image intensifier. Therefore, the illuminator's spectral emission specification needs to match only with the upper band range (1.4 to 2.2 microns). The upper band range is quite far from the visible spectrum and illumination in these wavelengths is safe even for highway applications. Near-infrared cameras **11** and **12** provide clear imaging signals even in foul weather conditions such as hazy conditions. These particular infrared bands of detection and illumination provide for sufficient light transmission through windshields, side windows, fog, and darkness. This permits adequate detection of humans in vehicles at night and in poor weather.

The image outputs **15** and **16** of cameras **11** and **12**, respectively, go to a weighted difference software process **17** or specialized hardware that fuses the outputs by performing weighted subtraction of the intensities of the two camera images. This weighted difference software or hardware may be referred to as a fuser. Such fusion of the camera outputs intensifies the silhouette of face **13** and other exposed human skin in the resultant fused image. Also, the image features a diminution of the background of the scene being covered by the cameras. This increased contrast between the person and the background in the fused image permits essentially perfect image segmentation through thresholding by a software process **18**, or specialized hardware. This thresholding software or hardware may be referred to as a thresholder. The output of the thresholder **18** may go to a display **19**, printer, or a post-process or specialized hardware.

A final processed image shows the exposed skin parts, such as face **13**, as binary blob **13'**, as shown in FIG. **1**. Background **20** of sensed face **13** is discounted as shown by blank background **20'** in display **19**. This clean-cut binary imagery ensures reliable and fast operation of a pattern recognition algorithm that identifies a human as indicated by face **13'** imagery.

FIG. **2**A illustrates the co-registration of cameras **11** and **12**. There is spatial and time registration between the cameras. The cameras could be of the same make and model. The necessary difference between the cameras is the optical bandwidth filters, **48** and **49**, which are situated between sensing arrays **46** and **47** and camera lens **58** and **59**, respectively, of cameras **11** and **12**. Filter **48** determines the 0.8 to 1.4 micron spectral sensitivity of array **46** in camera **11** and filter **49** determines the 1.4 to 2.2 micron spectral sensitivity of array **47** in camera **12**. A polarizer may be inserted in front of lens **58** of camera **11** and in front of lens **59** of camera **12**. Or instead, a polarizer may be inserted between lens **58** and array **46** of camera **11**, and between lens **59** and array **47** of camera **12**. Sensing arrays **46** and **47** of the cameras are the same size, for example, 512 by 512 pixels in a gallium arsenide substrate. Typically, the fields of view are the same for each array. Three pixels **51**, **52**, and **53**, for example, are selected out for spatial co-registration. Each of the three pixels are focused on corresponding portions **51'**, **52'**, and **53'**, respectively, of image **20** viewed by cameras **11** and **12**. That means the arrays have the same images, pixel for pixel, even though the spectral sensitivities are different. In other words, the columns and rows of pixels are aligned with the physical world scene, pixel for pixel. Once spatially co-registered, cameras **11** and **12** are kept stationary relative to the physical world.

Time co-registration of the cameras means that the cameras are in synchronization with each other from a signal perspective. The signals for each of the two corresponding pixels go to a frame buffer at the same time. The retention of light for each pixel is in the micro-second range. A typical frame time is about 33 milliseconds, which is 30 frames per second. The transfer of pixel data may be parallel, line-by-line, or serial, pixel-by-pixel, or any other style of information transfer. There is a sync signal for cameras **11** and **12** to initiate and maintain their time co-registration.

The image outputs or pixel signals **15** and **16** go to a software process or specialized hardware **17** which provides a certain weighting to each of the pixels and fuses pairs of corresponding pixels from cameras **11** and **12**, respectively, into single pixels. The weighted differencing is performed pixel by pixel. Each result is the fused pixel of the two weighted differenced pixels. The weight difference equation for such fusing is

$$P(i,j)_{fused}=P(i,j)_{lower\ band}-C*P(i,j)_{upper\ band},$$

P is spectral power. The position or location of each pixel in the respective image is identified by row (i.e., "i") and column (i.e., "j"). The rows and columns of pixels of the images of cameras **11** and **12** coincide with each other. The lower band pixels are those from camera **11** and the upper band pixels are those from camera **12**. The spectral power "P" for each pixel at i,j is indicated, for example, by a numeral scale of brightness from 0 to 255 for 8-bit resolution. "0" is entirely black or dark (i.e., no spectral power) and "255" is entirely white or bright (i.e., full spectral power). Numerical indications in between 0 and 255 are, of course, representative of various gradations of gray, brightness, or spectral power. "C" of the equation is a constant (i.e., weighting factor), which is determined according to the lighting of background or scene **20** and object or face **13**. "C" for daytime lighting conditions is about 3 for optimal results. "C" for nighttime depends upon the spectral distribution and properties of an artificial illuminator **14**.

The brightness or spectral power of a typical pixel of the lower band (image **46**) may be 55 and the brightness or spectral power of the corresponding typical pixel of the upper band (image **47**) may be 10. These upper and lower band pixel values are representative of skin in the corresponding bands. The spectral power of a resulting typical fused pixel, in daytime viewing, at a location of row i and column j in the daytime is determined with the following calculation.

$$P(i,j)_{fused}=55-3*10$$

$$P(i,j)_{fused}=55-30=25$$

The fused pixel signals go from software process or specialized hardware **17** to software process or specialized hardware **18** for image segmentation via thresholding of the fused pixels. Process or specialized hardware **18** emulates a comparator-like circuit in that each fused pixel below a certain threshold value (T) is assigned a value (V_1) of 0 and each fused pixel above the certain threshold value is assigned a value (V_2) of 255.

FIG. **3** shows a histogram of an image frame of fused pixels. The number of pixels for each spectral power value is indicated by curves **54** and **55** for a given sensed image. The pixels of curve **54** represent background **20** and the pixels of curve **55** represent human skin **13**. Curves **54** and **55** intersect at **56** that is deemed to be the appropriate value

for thresholding. If curves **54** and **55** do not intersect, then the thresholding value **56** is centered between curves **54** and **55**. The threshold value is dynamic in that it changes from frame to frame, and is determined for each image frame according to the histogram of the respective frame. If the spectral value for thresholding is 20, then fused pixels having a value below 20 are valued at 0 and fused pixels having a value above 20 are valued at 255. The resulting image in display **19** has white pixels for background **20'** and black pixels for face **13'**. This image may be reversed by process or specialized hardware **18** such that background **20'** has black pixels and face **13'** has white pixels.

FIG. **2**B shows an alternate embodiment for co-registration of the cameras **11** and **12**. As shown therein, an optical device **57**, e.g., a beamsplitter/filter device, is used to provide co-registration of the cameras. The setup is essentially the same as that shown in FIG. **2**A, except that the filters **47**, **48** are not provided with the cameras **11** and **12**. Instead, filtering is provided by the optical device **57**.

As shown in FIG. **2**B, light comes from the environment through the beamsplitter/filter optical device **57** to the two near infrared cameras **11** and **12** as represented by the points of light **51-53**. The beamsplitter/filter optical device **57** is an optical device with a coating that performs optimally at a specific angle. The beamsplitter/filter optical device **57** directs light with wavelengths below 1.4 microns (i.e., the lower band) to camera **11** and light with wavelengths above 1.4 microns (i.e., upper band) to the other camera **12**. The cameras **11**, **12** are preferably connected to a computer for processing video information. However, another electronic device or a human operator may be used as an alternative to, or in addition to, the computer device. The lower and upper bands are bounded either by the beamsplitter/filter optical device's **57** sensitivity or the camera's **11**, **12** sensitivity. Preferably, the lower band is 0.8 microns to 1.4 micron, and the upper band is 1.4 microns to 2.4 microns. However, other somewhat different ranges may work as well.

The beamsplitter/filter optical device **57** provides at each point in time, two co-registered frames in the upper and lower band at the hardware level of the system. Therefore, no time-consuming and generally complicated software to accomplish time registration is required like in the embodiment described above with reference to FIG. **2**B.

Further, a computer controlled near-infrared illumination source may be added to the system to maintain optimal illumination levels in the scene at all times. For example, a photometer may be used to sense scene illumination and provide a signal to initiate the need for computer adjustment of the illumination source.

As one can note here, a main application of the invention is people detection in vehicles. However, people detection can be used at security points, alert areas, and so forth. An enhanced version of system **10** may be used to actually identify people.

The spectrums in which cameras **11** and **12** function are within the reflected infrared portion **21** in FIG. **4**, which shows the EM spectrum. Visible spectrum **22** is the spectral sensitivity of conventional cameras. Unfortunately, visible light cameras have noise levels that increase during poor environmental conditions such as bad weather, nighttime, and direct sunlight. Some problems, such as nighttime viewing may be overcome with artificial lighting, which matches the visible spectrum of the camera, and which in vehicle occupant detection is a serious distraction to drivers. Another disadvantage is that a human face **13**, which is the object of interest, does not have consistent qualities within the visible range. Vehicle occupant faces appear dark or light, depending on the physiological characteristics of the occupant, and the intensity and incident angle of illumination.

The thermal infrared band **23** (3.0 to 5.0 and 8.0 to 14 microns) is associated with thermal properties of materials. The human body is at a temperature of 37 degrees C. This means that human faces have a consistent light color in thermal infrared imaging, despite various facial colors, which is contrary to visible imaging.

The thermal property of the body provides a clear differentiator from look-alike dummies. The thermal infrared sensor can function at night without an external illuminator. One disadvantage of using the thermal infrared band **23** for occupant detection is that vehicle windshield glass greatly attenuates infrared light transmission at 2.8 microns and higher.

FIG. **5** reveals the transmittance characteristics of infrared light between 0.4 and 2.8 microns for a clean vehicle windshield (curve **24**) and a dirty windshield (curve **25**). Beyond 2.8 microns of thermal infrared bandwidth **23**, the radiation transmittance characteristic of windshield glass is almost zero. The transmittance of a lightly tinted side window of a vehicle is good (50 to 85%), from 0.3 up to 2.8 microns as revealed by curve **26** in FIG. **6**. Between 2.8 and 4.3 microns, the radiation transmittance is about 20 percent for the side vehicle window. Beyond 4.3 microns the transmittance drops to nearly zero. However, the spectral behavior of the side window permits transmittance of some thermal radiation.

Curves **27** and **28** of FIG. **7** show the percentage of reflectance of infrared light for light and dark complexion Caucasian males, respectively. The reflectance is good between 0.6 and 1.4 microns. Above 1.4 microns, the reflectance is significantly diminished. However, the difference of reflectance of light and dark complexions are minimal.

In FIG. **8**, curves **29** and **30** show skin reflectance for light and dark complexions, respectively, of Asian males. Curves **31** and **32** of FIG. **9** show skin reflectance for light and dark complexions of black males. Even though the reflectance of light complexions is higher than those of dark complexions; curves **27**, **28**, **29**, **30**, **31** and **32** of FIGS. **7–9**, respectively, have similar shapes and all of them drop off at about 1.4 microns. These reflectances show some variation for all complexions of the Caucasian, Asian, and black males, between 0.6 and 1.4 microns.

Curves **33** and **34** of FIG. **10** show the reflectance for more extreme differences of light skin and dark skin, respectively. The reflectance of light and dark skin are significant up to 1.4 microns. After 1.4 microns, reflectance curves **33** and **34** for light and dark skin, respectively, become almost coincident and the resultant reflectance drop below 20 percent. Thus, in the near-infrared bands of 1.4 and above, the reflectance of detected humans of all kinds of skin shade, are about the same at wavelengths greater than 1.4 microns.

In FIG. **11**, curves **35**, **36**, and **37** show the reflectance for cotton, wood, and polyamide respectively, to be significant not just between 0.6 and 1.4 microns, but beyond 1.4 microns. The insignificant drop in reflectance after the 1.4 micron threshold point, is a basis that shows a large contrast in reflectance between the human face and inanimate objects, such as upholstery, the dashboard, and fabrics in a vehicle, which are background, and provide for easy detection of the human face in the range of 1.4 to 2.2 microns.

Consequently, there is a significant contrast, in reflectance between the images of a Caucasian male and a dummy head from a camera operating in the range between 1.4 and 2.2

microns. The image of the dummy is reflective and appears rather bright and the male human image is dark and thus the resultant contrast between the two images is rather stark. This person detection scheme is much superior to visible light imaging, since the latter scheme reveals little or no contrast between the Caucasian and dummy heads of like colors. In summary, it is easy to distinguish images of the human head from those of the dummy head in the 1.4 to 2.2 micron range imagery, but not easy to distinguish the images of the respective heads from each other in the 0.8 to 1.4 micron range imagery.

The lower reflectivity of human skin for the 1.4 to 2.2 micron spectral range is explained by the spectral reflectance of distilled water as shown by curve **38** of FIG. **12**. There is a substantial drop in reflectance at about 1.4 microns. Beyond 1.4 microns, the water absorbs substantial infrared radiation and appears in an image as a dark body. Since the composition of the human body consists of 70 percent water naturally, its spectral response is similar to that of water. So camera **12**, operating in the 1.4 to 2.2 micron range, captures this unique human body differentiator. With the operating range of camera **12**, one can safely use during nighttime a matching near-infrared illumination source **14** to improve the quality of the sensed image of face **13**. This light is invisible to humans, such as vehicle drivers, but also is harmless to their eyes since the wavelength of illuminator **14** is above the safe threshold of 1.4 microns.

Also, since cameras **11** and **12** of system **10** operate at a lower band than the mid-infrared band, glass penetration is not a problem and cameras **11** and **12** can easily detect through the frontal windshield of a vehicle. Thus, speed requirements for cameras **11** and **12** are less restrictive. In an actual highway site, a zoom lens would be used.

FIG. **13** shows a layout of a near-infrared system **40** for determining the speed characteristics of the human detector. A vehicle **41** may be assumed to be moving down a highway at a velocity v, as shown by vector **42**, and be observed in a frontal view with a near-infrared camera **11** or **12** at a distance d, as shown by line **43**, and from a height h, as shown by line **44**. Only one of the cameras **11** and **12** is needed for this evaluation, but it may be either one of them. Camera **11, 12** may be a Sensors Unlimited Inc. SU 320 equipped with a telephoto lens, a band-pass filter in the range 1.4 to x microns (where x>1.4 microns), and a polarizing filter to reduce the glare effect from the sun illumination during daytime.

During the daytime, system **40** uses the illumination of the sun. The objective is to determine if there is any appropriate geometric arrangement for camera **11, 12** so that the signal to noise (S/N) ratio and the camera speed are kept at acceptable levels even under adverse conditions. An acceptable (S/N) ratio is considered anything above 35. The speed quality is considered acceptable when the image smearing does not exceed the width of one pixel.

The first step in a radiometric computation is to determine the amount of radiation that falls upon the objects of interest such as the occupants of vehicle **41**. The spectral band considered is above the 1.4-micron threshold point. Because of constraints due to the quantum efficiency of the camera SU-320 that was used in the actual experiments, one limits the spectral band in the range of 1.4 to 1.7 microns. Slightly modified things are in effect for the extended range of 1.4 to 2.2 microns. The spectral irradiance of the sun (the illumination source) on a clear day at sea level is approximately I_{sunny}=0.008 Watts/cm^2 in the 1.4 to 1.7 micron band range. In this computation, however, one considers the worst case scenario of an overcast day. For an overcast day, the irradiance value is reduced by 10^{-3} thus giving irradiance at vehicle **41** of approximately

$$\begin{aligned} I_{overcast} &= 10^{-3} * I_{sunny} \\ &= 10^{-3} * 0.008 \\ &= 8\ \mu\text{Watts/cm}^2. \end{aligned}$$

The transmittance in this spectral range of windshield **45** of vehicle **41** is approximately 0.4 resulting in an irradiance on the vehicle occupants of

$$\begin{aligned} \backslash[AutoLeftMatch]\ I_{occupant} &= 0.4 * I_{overcast} \\ &= 0.4 * 8 \\ &= 3.2\ \mu\text{Watts/cm}^2. \end{aligned}$$

The second step in a radiometric computation is to determine how much of the incident radiation on the objects of interest is reflected back to the sensor (i.e., near-infrared camera **11, 12**). The radiance into a hemisphere assuming a reradiate of 0.4 would be

$$\begin{aligned} R_{occupant} &= 0.4 * I_{occupant} / \pi \\ &= 0.4 * 3.2 / \pi \\ &= 0.4\ \mu\text{Watts/cm}^2 - \text{steradian}. \end{aligned}$$

This represents the reflected portion of the occupant irradiation. The occupant's body absorbs the rest. The reflected radiation has to pass through windshield **45** and the camera **11, 12** lens to reach the near-infrared sensor array of camera **11, 12**. One assumes a 0.4 windshield transmittance, a f/2 camera lens (i.e., having a 14.32° cone angle) with 0.8 transmittance, a polarizer with 0.4 transmittance, and a band-pass filter with 0.6 transmittance. Then, the irradiance at the sensor array of camera **11, 12** will be

$$\begin{aligned} I_{camera} &= 0.4 * 0.8 * 0.4 * 0.6 * \pi * R_{occupant} * \sin^2(14.32°) \\ &= 0.4 * 0.8 * 0.4 * 0.6 * \pi * 0.4 * \sin^2(14.32°) \\ &= 0.006\ \mu\text{Watts/cm}^2. \end{aligned}$$

Camera **11, 12** has square pixels with a side of 37.5*10^{-4} cm or an area

$$\begin{aligned} A &= 37.5 * 10^{-4} * 37.5 * 10^{-4} \\ &= 1.40 * 10^{-5}\ \text{cm}^2. \end{aligned}$$

Consequently, the radiant power on the camera **11, 12** pixel will be

$$\begin{aligned} P_{pixel} &= A * I_{camera} \\ &= 1.4 * 10^{-5} * 0.006 \\ &= 0.084 * 10^{-12}\ \text{Watts}. \end{aligned}$$

The camera's detectivity D* is D*=10^{12} cm √Hz/Watts. The noise equivalent power (NEP) is related to detectivity D*, pixel area A, and electronic bandwidth Δf by the following equation:

$$NEP = (A/\Delta f)^{1/2}/D^*.$$

The bandwidth Δf is determined by the exposure time of camera **11, 12**. The exposure time depends on vehicle **41**

velocity **42**, camera range **40**, and the camera **11**, **12** field of view such that the images smear less than 1 pixel. Assuming vehicle **41** traveling at a speed of 65 mph, at a distance d **43** of 40 meters (m) away from camera **11**, **12**, and with a field of view of 1.6 m, the 320×240 pixel array of camera **11**, **12** gives a maximum exposure time of 1 ms or a bandwidth of Δf=1 kHz. Substituting the values for A, Δf, and D* in the formula of NEP, one gets

$$NEP=1.18*10^{-13} \text{ Watts.}$$

Therefore, the signal to noise ratio S/N will be

$$S/N=(P_{pixel}/NEP)=0.7.$$

In conclusion, assuming a worst case scenario (overcast day, dirty windshield, dark occupant skin) one determines that camera **11**, **12**, equipped with a f/2 lens, a 1.4 to 1.7 μm filter, and a polarizer, if it is positioned at a distance **43** of d=40 m from incoming car **41** and at a height **44** of h=7 m at the specified distance **43**, will achieve an acceptable smear of less than one pixel because the required exposure time of 1 ms is within the camera's speed capabilities. The signal to noise ratio (S/N) is 0.7. To boost the S/N ratio to a higher value on overcast days, one needs to employ an illumination source **14**. Illumination source **14** will also be helpful during nighttime. If one operated in the visible spectrum, the use of an illuminator in the high occupancy vehicle (HOV) lane would be prohibitive. Fortunately, in this case, the spectral signature of illuminator **14** for the 1.4 to 1.7 micron waveband can be safely employed in the HOV lane.

Post processing includes a neural network that performs automatic vehicle occupant detection. The vehicle occupant detection approach is based upon a fuzzy neural network algorithm. The perfect binary image provided by the fusion approach described above facilitates high correct detection rates.

Further, with reference to several previous Figures, and also FIGS. **14–20**, disguise detection systems and methods are described wherein reflection properties of natural human anatomy (e.g., natural skin and hair) in the upper band of the near-infrared spectrum are used to provide for disguise detection, e.g., the detection of the presence of artificial materials associated with the head of the human body.

The human skin has extremely low reflectance in the upper band of the near-infrared spectrum (i.e., 1.4 μm and greater in the near infrared spectrum) as previously described herein with reference to FIGS. **7–10**. Such FIGS. **7–10** showed that human skin has a high reflectance between 0.6 and 1.4 microns. However, above 1.4 microns, the reflectance is significantly diminished. Since almost everything else in a typical scene has a higher reflectance in the upper band of the near-infrared spectrum greater than 1.4 μm, there is sharp contrast between the human skin, e.g., face and neck, and the background.

Further, as shown by FIGS. **7–10**, the skin reflectance property, i.e., that the reflectance of human skin above 1.4 microns in the upper band of the near infrared spectrum is significantly diminished, is universal across the human race, e.g., there is little difference in such reflectance properties above 1.4 microns in the upper band of the near infrared spectrum when comparing Caucasian, asian, and black persons. For example, FIG. **7** shows a drop-off in reflectance at or about 1.4 microns for Caucasian males, FIG. **8** shows such a drop-off for asian males, FIG. **9** shows such a drop-off for black males, and FIG. **10** shows the drop-off for extreme differences of light skin and dark skin. As such, and as previously described herein, in the near-infrared band of 1.4 and above, the reflectance of natural skin of detected humans of all kinds of skin shade are about the same at wavelengths greater than 1.4 microns.

In contrast to the natural skin, human hair, i.e., natural hair, is highly reflective in the upper band of the near infrared spectrum above 1.4. Such reflectance is also a property that is universal across the human race. The highly reflective nature of human hair in the upper band of the near infrared spectrum above 1.4 microns is generally shown in FIG. **17**. In FIG. **17**, a reflectance diagram of natural human hair in at least a portion of the near-infrared spectrum is shown. Three separate reflectance measurements on a natural human hair specimen produced the high reflectance properties shown in the diagram.

In contrast to the high reflectance of natural human hair, a reflectance diagram of a human hair hairpiece (an artificial material as later defined herein) is shown in FIG. **18**. As shown therein, in the upper band of the near-infrared spectrum, reflectance is much lower than natural hair. Even if true human hair is used to be fitted in a toupee, due to the chemical processing used in making a toupee, the reflective characteristics are altered. Although the difference in reflectivity when comparing a true human hair wig to true natural human hair is much subtler, such reflectivity differences are still substantial and can be easily captured.

In addition, the reflectance of various artificial materials, such as those used in disguises and as generally defined below (heavy make-up, artificial face parts, add-on hair, etc.) generally have a reflectance that is significant beyond 1.4 microns. For example, as shown in FIG. **11**, and previously described herein, the reflectance properties for cotton, wood, and polyamide do not drop significantly in reflectance after the 1.4 micron point. As such, there is a significant contrast in reflectance properties between natural human skin and other artificial materials, and also between natural human hair and artificial materials, in the upper band of the near infrared spectrum.

Yet further, as previously described herein, radiation in both the upper and lower near-infrared bands can transmit through the window glass of vehicles. Therefore, this is a definite advantage compared to both the visible and the thermal infrared spectrums. As such, the present invention which uses the upper band of the near-infrared spectrum can detect disguised faces even within vehicles. The transmission characteristics through the window glass of vehicles is shown in the diagrams of FIGS. **5** and **6**. As shown therein and as described previously herein, FIG. **5** reveals the transmittance characteristics of infrared light between 0.4 and 2.8 microns for a clean vehicle windshield (curve **24**) and a dirty windshield (curve **25**). Beyond 2.8 microns at the beginning of the thermal infrared bandwidth, the radiation transmittance characteristic of windshield glass is almost zero. However, transmittance at less than 2.4 microns is very good. The transmittance of a lightly tinted side window of a vehicle is good (50 to 85%), from 0.3 up to 2.8 microns as revealed by curve **26** in FIG. **6**. As such, transmittance levels in the upper band of the near-infrared region below 2.8 microns are very good.

The present invention uses at least a portion of the upper band of the near infrared spectrum. As used herein, the upper band of the near-infrared spectrum includes the range from 1.4 microns to 2.8 microns. As previously indicated herein, at 2.8 microns thermal energy begins to appear. Preferably, according to the disguise detection systems and methods described herein, at least a portion of the upper band of the near-infrared spectrum within the range of 1.4 microns and above is used. More preferably, at least a portion of the

upper band of the near-infrared spectrum within the range of 1.4 microns to 2.4 microns is used. Yet more preferably, at least a portion of the upper band of the near-infrared spectrum within the range of 1.4 microns to 1.7 microns is used.

One skilled in the art will recognize that slightly shorter or longer ranges can also yield acceptable detection results. For example, with respect to the ranges given above, a deviation from such wavelength values which may produce acceptable detection results is contemplated to fall within the specified ranges.

Further, as used herein, artificial materials include any materials other than natural skin and/or natural hair, such as those items or materials used for disguise purposes. For example, wigs, make-up materials, artificial nose pieces, etc., formed from one or more artificial materials or inanimate objects such as polymers, fibers, etc., are referred to herein as artificial materials. Further, background objects are also referred to herein as artificial materials, e.g., a car behind a person, clothing of a person, etc.

Generally in disguise situations, an individual alters his or her facial appearance through the addition/application of a fake nose, make-up, wig, artificial eyelashes, and the like. Professional actors routinely use this method for needs of their acting roles. A well done disguise by this technique is very difficult or impossible to be detected in the visible spectrum. Generally, the face has been touched with a make-up material to integrate smoothly the fake nose. Although disguises are usually very simplistic, the facial appearance of the person changes substantially. As such, there is no way to visually detect the deception without prior knowledge.

Detection systems and methods described herein are able to detect disguises due to the fact that any artificial materials applied to the head of the human, e.g., facial skin or scalp, alters to various detectable degrees the respective unique infrared signatures of such humans, particularly in the upper band of the near-infrared spectrum. Therefore, although disguise configurations can easily fool the eye in the visible spectrum, such disguises are immediately apparent in the upper band of the near-infrared spectrum.

The reflectance characteristics of various artificial materials, and also natural hair and natural skin of the human body, as described above can be more clearly understood through the display of such reflectance characteristics as shown or described further below with reference to FIGS. **14**A–B and FIGS. **15**A–B. FIG. **14**A shows an undisguised human head **102** in a visible spectrum. The human head **102** includes a facial portion **114** of natural skin and natural human hair **112** including a beard, a mustache, eyebrows, and scalp hair.

FIG. **14**B shows the undisguised human head **102** in the upper band of the near-infrared spectrum based on the reflectance properties in the scene. In the upper band of the near-infrared spectrum, the natural human skin of the facial portion **114** has a dark appearance due to its low reflectance characteristics. On the other hand, the facial hair **112** including the beard, mustache, eyebrows, and scalp hair has a bright appearance due to its highly reflective nature in the upper band of the near-infrared spectrum. As such, the undisguised person has a unique near-infrared signature due to the reflectance characteristics of the person's natural hair and natural skin in the upper band of the near-infrared spectrum. As previously described herein, such characteristics are universal for the entire human species.

FIG. **15**A shows a disguised human head **106** in the visible spectrum. The disguised human head **106** includes a facial portion **116** having natural skin but with a fake nose **117** fitted thereon and touched up by make-up. Further, the disguised human head **106** includes a wig **118** covering the scalp of the human head and a fake beard **108**. Natural hair components **119** include the eyebrows and mustache.

Such a disguise is not detectable in the visible spectrum, as shown in FIG. **15**A. However, the artificial materials alter radically the signature of the person's head in the upper band of the near infrared spectrum. As a result, facial skin appears very bright in the area of the fake nose **117**, and is an obvious abnormality in the upper near-infrared band as shown in FIG. **15**B. In contrast, the artificial hair wig and beard has much lower reflectivity than natural human hair in the upper band of the near-infrared spectrum. As a result, the artificial hair **108**, **118** of the human head **106** appears very dark in the image, due to its low reflectivity, and the natural hair, i.e., the mustache and eyebrows **119**, appear bright.

Such abnormalities are readily detectable, as can be seen in FIG. **15**B. In FIG. **15**B, the human head **106** shows the abnormal dark hair **118** covering the scalp and abnormal dark beard **108**. If such hair were natural hair, it would have a similar brightness as that shown in FIG. **14**B and like the natural hair **119** including the eyebrows and mustache. Likewise, further, the artificial materials used to form the fake noise **117** are clearly abnormal due to their high reflectivity compared to the other natural skin facial portion **116**.

As described above, it can be readily seen that an imaging system based on the reflectivity in the upper band of the near-infrared spectrum provides advantageous disguise detecting ability. Such a system and method is based on various reflectivity characteristics in the upper band of the near-infrared spectrum. Such characteristics include at least: that the human skin has very low reflectivity in the upper band of the near-infrared spectrum and always ranks amongst the darkest objects in the scene; that artificial materials, e.g., facial disguise materials, feature high reflectivity in the upper band of the near-infrared spectrum and always rank among the brightest objects in the scene and, as such, when they are applied to natural skin and hair of the human head, they alter totally its phenomenology and facilitate easy detection in the imagery by a human observer or a machine vision system; that the natural human hair has high reflectivity in the upper band of the near infrared spectrum and always ranks amongst the brightest objects in the scene; and further that artificial hair or even true human hair wigs feature low reflectivity in the upper band and always rank amongst the darkest objects in the scene and, as such, when they are applied to the scalp or to the face of a human head, they alter totally the expected phenomenology and facilitate easy detection in the imagery by a human observer or a machine vision system.

FIG. **16** shows one illustrative embodiment of a disguise detection system **130** according to the present invention. The disguise detection system **130** includes circuitry **132**, an upper near-infrared camera **134**, a photometer **140**, an upper near-infrared illuminator **136**, and a computer-controlled power supply **138**. The upper near-infrared camera **134** may be a camera like that previously described herein with reference to FIGS. **1** and **2**. The camera is sensitive to at least a portion of the upper band of the near-infrared spectrum, preferably in the range of 1.4 microns and above, more preferably in the range of 1.4 microns to 2.4 microns, and even more preferably in the range of 1.4 microns to 1.7 microns in the upper band of the near-infrared spectrum. Such cameras generally have a sensing array, for example, an array of pixels that provide signals based on the light

captured thereby, as is readily known to those skilled in the art. The pixel signals representative of the image based on the light captured is provided to circuitry **132**. For example, the upper near-infrared camera may be a camera available from Sensors Unlimited, under the trade designation SU-320.

Preferably, circuitry **132** includes a computer system **133** operable to execute software to provide a user with information as to the presence of an artificial material associated with the head of the human body based on the detected reflection in the upper band of the near-infrared spectrum. Although the circuitry **132** may be implemented using software executable using a computer apparatus, other specialized hardware may also provide the functionality required to provide a user with information as to the presence of an artificial material associated with the head of the human body, e.g., information concerning a disguise. As such, the term circuitry as used herein includes not only specialized hardware, but may also include circuitry such as processors capable of executing various software processes.

For example, the computer system **133** may be any fixed or mobile computer system, e.g., a personal computer or a minicomputer. The exact configuration of the computer system is not limiting and most any device capable of providing suitable computing capabilities may be used according to the present invention. Further, various peripheral devices, such as a computer display, a mouse, a keyboard, memory, printer, etc., are contemplated to be used in combination with a processing apparatus of the system.

The detector or photometer **140** is operable to detect an illumination level proximate the head of the human body which is in the scene being captured by camera **134**. The photometer **140** provides information to the computer system **133** based on the detected illumination level. The computer system **133** is operable to control the upper near-infrared illuminator **136** which is an illumination source matched to the upper band of the near-infrared spectrum used to perform the method according to the present invention. The upper near-infrared illuminator **136** is positioned to illuminate at least a portion of the head of the human body, e.g., the scene in which the human body is located. The circuitry **132**, e.g., the computer system **133**, is operable to control the upper near-infrared illuminator **136** based on the detected illumination level provided by the photometer **136** to maintain a desired illumination level of the head of the human body, e.g., illumination of the scene in which the human body is located. In one embodiment, software of computer system **133** may be used to automatically adjust the illumination level of the upper band near-infrared illuminator **136** to maintain an optimal illumination level in the scene at all times. The adjustment of the illumination level is based on the readings from photometer **140** and may be realized through power supply **138**.

The illumination assists in the production of a high quality imaging signal from the camera **134**, even during overcast days and at night. Such illumination can be used because the scene can be safely illuminated with such eye-safe near-infrared illuminators. Also, since the eye is not sensitive to the near-infrared spectrum, the system remains stealth at all times. Any suitable photometer and illuminator may be used to provide for suitable illumination of the scene in which the human body being captured by the camera **134** is located.

Both the camera **134** and illuminator **137** may be moved by any suitable structure represented by arrows **135** and **137**, respectively, such that a larger field of view may be possible. For example, the camera **134** may be moveably mounted for capturing images in a 180° field of view, and likewise illuminator **136** may be moved so as to provide adequate illumination to achieve an imaging signal from camera **134** of sufficient quality to perform disguise detection.

Using a detection system such as, for example, the disguise detection system **130** of FIG. **16**, various methods of determining the presence of an artificial material associated with the head of the human body based on the detected reflection may be performed. Two illustrative embodiments of such methods are shown in FIGS. **19** and **20**. The method **150** shown in FIG. **19** provides for detection by a human observer, such as by viewing displayed images as shown in FIGS. **14** and **15**. FIG. **20** shows an illustrative embodiment of a method **160** which includes additional processing of the data to provide additional information to the user other than just displayed images, e.g., such as information that may be provided using a machine vision system, or other information instead of displayed images.

The method **150**, illustratively shown in FIG. **19**, will be described with reference to the displayed images of FIGS. **15**A and **15**B. The method **150** includes initiating the disguise detection system (block **152**). Upon initiating the disguise detection system (block **152**), image data representative of the reflection in at least a portion of the upper band of the near-infrared spectrum is captured by camera **134**. The reflection data from camera **134**, e.g., pixel signal data, is provided to the circuitry **132**, e.g., a computer system **133**, which may operate on the data using a thresholding process (block **154**) so as to manipulate the data and to provide an image to be displayed for viewing by a user (block **156**).

Various thresholding techniques have been used as is readily known to those skilled in the art. Any suitable thresholding process that provides for acceptable segmentation of dark and light regions may be used according to the present invention. In general, such thresholding processes compare the data representative of the reflection to one or more thresholding values. Such values may be based on a variety of factors, such as the reflection characteristics of natural skin, of natural hair, etc. For example, a thresholding process described in the article entitled "A Threshold Selection Method from Gray-Level Histograms" by Otsu, *IEEE Transactions on Systems, Man And Cybernetics*, Vol. SMC-9, No. 1, January 1979, may be used according to the present invention. The thresholding process generally involves a non-parametric and unsupervised method of threshold selection. An optimal threshold is selected so as to maximize the separability of the resultant classes in gray levels. The algorithm utilizes only the zeroth-order and the first-order cumulative moments of the gray level histogram. The speed of the system, in part because of the thresholding process, can provide real time images to the user.

The user when presented with the displayed image such as shown in FIGS. **14**B and **15**B (block **156**) can then view any abnormal characteristics of the image, e.g., the bright nose feature **117** representative of a fake nose, the dark facial hair features **108** and **118** which are abnormally dark compared to natural hair, etc. as shown in FIG. **15**B. Upon detection of such abnormalities by the user, appropriate action may be taken. Such action may include the sounding of an alarm, direct contact with the disguised individual, etc.

In such a method **150**, there may be a direct correlation between the level of reflectance and the brightness of features like that represented in FIG. **15**B, e.g., high level of reflectance being shown as bright feature. However, additional processing in conjunction with the thresholding process may be used to display detected artificial materials in any differentiating manner. For example, the skin **116** may actually be represented as a first shade and the nose being

abnormally represented as a different shade easily recognized by a user. For example, the brightness of the portions of the image may be reversed from that shown in FIG. **15**, e.g., the fake nose is dark and the skin is brighter than the fake nose.

The method **160**, illustratively shown in FIG. **20**, includes initiating the disguise detection system (block **162**). Once the data has been captured by camera **134** and provided to the computer system **133**, the reflectance data, e.g., pixel signal data, from camera **134** is analyzed (block **164**). The data may be analyzed in one or more different manners.

In one illustrative embodiment, for example, the data may be compared to one or more threshold levels. The one or more threshold levels (block **166**) provided for comparison to the reflection data may be threshold levels based simply on the natural skin and natural hair reflectance characteristics. However, such threshold levels may also be based on a plurality of reflectance properties of the artificial materials themselves used in disguises. As such, the reflectance characteristics of a number of known disguise materials can be mapped into a multi-level thresholding algorithm. With use of such a multi-level thresholding algorithm, not only can detection of disguises be attainable, the detection and existence of specific materials used in the disguises may be obtained by the detection of reflectance and comparison using the multi-level thresholding algorithm.

For example, reflectance measurements in the upper band of the near-infrared spectrum may be gathered for all known possible disguise materials used in the trade. A direct mapping between different artificial materials and thresholding levels corresponding to a particular reflectance characteristic can be performed. Likewise, various other disguise situations may be mapped. For example, a list of facial images featuring just a single disguise item, e.g., a fake mustache only or a heavy make-up only, may be mapped. As will be recognized, the list of disguises which may be mapped is unlimited, however, a multi-level thresholding scheme can be developed that may be used to identify any number of various disguises. As such, with the use of a multi-level thresholding scheme, the identification of one or more artificial materials associated with the head of the human body can be identified and the user alerted to the presence of such artificial materials (block **168**). For example, upon comparing the reflection data from the camera **134**, with use of computer system **133**, to such a multi-level threshold reference map, an alert may be presented to the user indicating the presence of an artificial material associated with the head (block **168**). The user may then take appropriate action.

The user may be alerted in any number of ways. For example, information may be displayed, a silent alarm may be used, an audio alarm, a tactile alarm, etc. Such information displayed may include, for example, an alarm mechanism, information as to the disguised person, the disguised materials being used, and/or the level of security risk involved with the disguised person.

It will be recognized that various methods and systems described herein may be used in combination and/or such methods and systems may be used in combination with other detection systems. For example, in one illustrative embodiment of such a combined system according to the present invention, reflections from a scene in at least a portion of one band of the near-infrared spectrum may be detected. The presence of the head of the human body in a scene may be determined based on the detected reflection in the portion of the one band of the near-infrared spectrum, e.g., segmentation of the head from the background of a scene. Thereafter, the reflection from at least one portion of the head of the human body in at least a portion of an upper band of the near-infrared spectrum may be detected to determine the presence of an artificial material associated with the head of the human body based on such reflection.

For example, such a combination system and method may be implemented using the two camera system previously described herein. For example, the dual band near-infrared method may be used for face detection for the location of a head. Thereafter, the disguise detection method may be used to determine the presence of an artificial material.

Further, for example, in another embodiment of such a combination system and method, the head may be determined to be present by detecting the reflection from a scene in at least a portion of the upper band of the near-infrared spectrum. For example, the upper band of the near-infrared spectrum within the range of 1.4 μm to 2.2 μm may be used to determine the presence of the human head such as described previously herein, e.g., wherein a dummy head is differentiated from the human head or a human head is differentiated form a background. Further, thereafter, it may be determined whether the human head is disguised also using the upper band of the near-infrared spectrum, as previously described herein.

Such methods and systems may be used in combination with other systems and methods such as those that employ thermal infrared detection. Thermal infrared detection may be used for detecting cosmetic surgery disguises. Such cosmetic surgery disguises may not be detectable by the disguise detection process using the upper band of the near-infrared spectrum, as previously described herein. Likewise, visible spectrum systems may be used in combination with the previously described methods and systems herein so as to enhance detection capabilities.

All patents and references cited herein are incorporated in their entirety as if each were incorporated separately. Although the invention has been described with particular reference to the preferred embodiments thereof, variations and modifications of the present invention can be made within a contemplated scope of the claims, as is readily known to one skilled in the art.

What is claimed is:

1. A detection system for use in detecting a human in a scene, the detection system comprising:

a first camera sensitive to a first band of wavelengths within a reflected infrared radiation range and operable to provide one or more frames of a first image output representative of the scene;

a second camera sensitive to a second band of wavelengths within the reflected infrared radiation range and operable to provide one or more frames of a second image output representative of the scene;

an optical device positioned to direct light reflected from the scene in at least the first band of wavelengths to the first camera and to direct light reflected from the scene in at least the second band of wavelengths to the second camera, wherein the one or more frames of the first image output are co-registered in time with the one or more frames of the second image output; and

a processing apparatus operable to detect a human in the scene based on the first and second image outputs.

2. The system of claim **1**, wherein the optical device comprises a combination beamsplitter and filter.

3. The system of claim **2**, wherein the optical device is an optical component having a coating thereon that directs light with wavelengths below about 1.4 microns to the first camera and light with wavelengths above about 1.4 microns to the second camera.

4. The system of claim 1, wherein the processing apparatus is operable to fuse spectral power of the pixels of the first image output with spectral power of corresponding pixels of the second image output to provide a fused image output having an increased contrast between a human and a background in the scene.

5. The system of claim 4, wherein the processing apparatus is further operable to segment the human from the scene by comparing the spectral power of each pixel of the fused image output to one or more threshold values.

6. The system of claim 1, wherein a difference in reflectance for human skin in the first band of wavelengths relative to the second band of wavelengths is greater than a difference in reflectance for objects other than human skin in the first band of wavelengths relative to the second band of wavelengths.

7. The system of claim 1, wherein the processing apparatus is further operable to perform a weighted difference calculation of spectral power of the pixels of the first image output with spectral power of corresponding pixels of the second image output resulting in a weighted difference output for the pixels.

8. The system of claim 7, wherein the processing apparatus is further operable to compare the weighted difference output for the pixels to one or more threshold values to differentiate pixels representative of human skin from pixels representative of objects other than human skin.

9. The system of claim 1, wherein said first and second cameras have the same fields-of-view.

10. A detection system comprising:

first camera means for sensing radiation of a scene within a first band of wavelengths in a reflected infrared radiation range and operable to provide one or more frames of a first image output representative of the scene;

second camera means for sensing radiation of the scene within a second band of wavelengths in the reflected infrared radiation range and operable to provide one or more frames of a second image output representative of the scene;

optical device means positioned for directing light reflected from the scene in at least the first band of wavelengths to the first camera means and for directing light reflected from the scene in at least the second band of wavelengths to the second camera means such that one or more frames of the first image output are co-registered in time with one or more frames of the second image output; and

processing means for detecting a human in the scene based on the first and second image outputs.

11. The system of claim 10, wherein the processing means comprises:

fusing means connected to said first and second camera means for fusing spectral powers $P(i,j)_1$ of pixels $(i,j)_1$ from said first camera means with spectral powers $P(i,j)_2$ of corresponding pixels $(i,j)_2$ from said second camera means, resulting in fused spectral powers $P(i,j)_f$; and

thresholding means, connected to said fusing means, for thresholding fused spectral powers $P(i,j)_f$ from said fusing means, resulting in threshold spectral powers $P(i,j)_t$; and

wherein:

the scene is focused by said first camera means on a first sensing array having m×n pixels;

the scene is focused by said second camera means on a second sensing array having m×n pixels;

each pixel is located at ith row and jth column;

$0 \leqq i \leqq m$; and

$0 < j \leqq n$.

12. The system of claim 11, further comprising indicating means for displaying a segmented image of the scene.

13. The system of claim 12, wherein:

$$P(i,j)_f = P(i,j)_1 - C * P(i,j)_2; \text{ and}$$

C is a constant determined according to a lighting condition of the scene.

14. The system of claim 13, wherein:

$$P(i,j)_1 = V_1 \text{ if } P(i,j)_f \geq T;$$

$$P(i,j)_t = V_2 \text{ if } P(i,j)_f < T;$$

V_1 is a first value;

V_2 is a second value; and

T is a threshold value, wherein T is determined by a spectral power distribution of fused pixels $(i,j)_f$.

15. The system of claim 10, wherein a wavelength between the first and second bands of wavelengths is about 1.4 microns.

16. The system of claim 10, wherein:

the first band of wavelengths is between about 0.8 and 1.4 microns; and

the second band of wavelengths is between about 1.4 microns and 2.2 microns.

17. A method for detecting humans, comprising:

focusing a scene on a first m x n pixel array that is sensitive to light of a first bandwidth within a reflected infrared radiation range resulting in one or more frames of a first image output representative of the scene and on a second m×n pixel array that is sensitive to light of a second bandwidth within the reflected infrared radiation range resulting in one or more frames of a second image output representative of the scene;

co-registering one or more frames of the first image output with one or more frames of the second image output, wherein co-registering the frames comprises using an optical device to direct light reflected from the scene in at least the first bandwidth to the first m×n pixel array at each of a plurality of points in time and directing light reflected from the scene in at least the second bandwidth to the second m×n pixel array at each of the plurality of points in time; and

using the first and second image outputs to detect a human in the scene.

18. The method of claim 17, wherein using the first and second image outputs to detect a human in the scene comprises fusing spectral power of the pixels of the first image output with spectral power of corresponding pixels of the second image output to provide a fused image output having an increased contrast between a human and a background in the scene.

19. The method of claim 18, wherein using the first and second image outputs to detect a human in the scene further comprises segmenting the human from the scene by comparing the spectral power of each pixel of the fused image output to one or more threshold values.

20. The method of claim 19, wherein the method further comprises displaying a segmented image.

21. The method of claim 17, wherein a wavelength between the first and second bandwidths is about 1.4 microns.

22. The method of claim 17, wherein the first bandwidth is between about 0.8 and 1.4 microns and the second bandwidth is between about 1.4 microns and 2.2 microns.

23. The method of claim **17**, wherein a difference in reflectance for human skin in the first bandwidth relative to the second bandwidth is greater than a difference in reflectance for objects other than human skin in the first bandwidth relative to the second bandwidth.

24. The method of claim **17**, wherein using the first and second image outputs to detect a human in the scene comprises performing a weighted difference calculation of spectral power of the pixels of the first image output with spectral power of corresponding pixels of the second image output resulting in a weighted difference output for the pixels.

25. The method of claim **24**, wherein using the first and second image outputs to detect a human in the scene further comprises comparing the weighted difference output for the pixels to one or more threshold values to differentiate pixels representative of human skin from pixels representative of objects other than human skin.

26. The method of claim **17**, wherein using the first and second image outputs to detect a human in the scene comprises:

fusing a spectral power $P(i,j)_1$ of each pixel of the first m×n pixel array with a spectral power $P(i,j)_2$ of each corresponding pixel of the second m×n pixel array, to result in a spectral power $P(i,j)_f$ of a fused pixel, respectively;

thresholding the spectral power $P(i,j)_f$ of each fused pixel into a first value if the spectral power is greater than a threshold value; and

thresholding the spectral power $P(i,j)_f$ of each fused pixel into a second value if the spectral power is less than the threshold value;

wherein:

$0<i\leqq m$; and

$0<j\leqq n$.

27. The method of claim **26**, wherein:

$$P(i,j)_f=P(i,j)_1-C*P(i,j)_2;\text{ and}$$

C is a constant dependent upon a lighting condition of the scene.

28. The method of claim **27**, wherein:

$$P(i,j)_i=V_1 \text{ if } P(i,j)_f>T;$$

$$P(i,j)_i=V_2 \text{ if } P(i,j)_f<T;$$

V_1 is a first value;

V_2 is a second value; and

T is a threshold value dependent upon a distribution of spectral powers $P(i,j)_f$ of the fused pixels.

* * * * *