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

(10) **Patent No.: US 9,335,255 B2**
(45) **Date of Patent: *May 10, 2016**

(54) **SYSTEM AND ASSESSMENT OF REFLECTIVE OBJECTS ALONG A ROADWAY**

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(72) Inventors: **James E. Retterath**, Excelsior, MN (US); **Robert A. Laumeyer**, Eden Prairie, MN (US)

(73) Assignee: **Facet Technology Corp.**, Eden Prairie, MN (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.

This patent is subject to a terminal disclaimer.

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(22) Filed: **Oct. 13, 2014**

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US 2015/0153271 A1 Jun. 4, 2015

Related U.S. Application Data

(60) Continuation of application No. 14/025,614, filed on Sep. 12, 2013, now Pat. No. 8,860,944, which is a division of application No. 13/205,337, filed on Aug. 8, 2011, now Pat. No. 8,660,311, which is a division of

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(51) **Int. Cl.**
G01N 21/55 (2014.01)
G01N 21/25 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01N 21/251*** (2013.01); ***G01N 21/55*** (2013.01); ***G01N 21/84*** (2013.01); ***G01S 17/06*** (2013.01); ***G08G 1/096758*** (2013.01); ***G08G 1/096783*** (2013.01); *G01N 2201/06113* (2013.01); *G01N 2201/12* (2013.01)

(58) **Field of Classification Search**
CPC G02B 5/124; G02B 1/04; G02B 1/105; G02B 1/18; G02B 2027/014; G02B 2027/0187; G02B 27/0101; G02B 5/0236; G02B 5/04; G02B 5/122; G02B 6/0018; G02B 6/0028; G02B 6/003; G02B 6/0065; G02B 6/00
See application file for complete search history.

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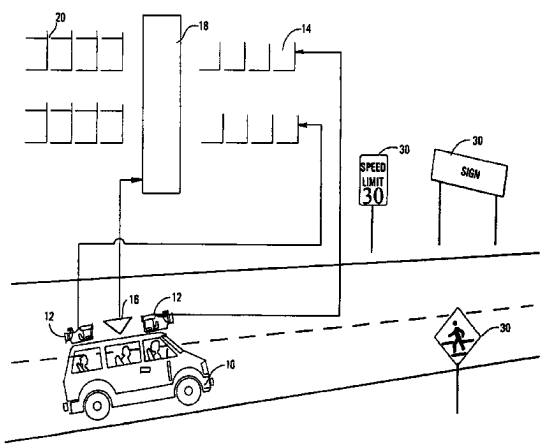
(Continued)

Primary Examiner — Michael P Stafira
(74) *Attorney, Agent, or Firm* — Patterson Thuente Pedersen, P.A.

(57) **ABSTRACT**

A system for the assessment of reflective surfaces disposed along a roadway repeatedly illuminates an area along the roadway that includes at least one reflective surface using a light source. Multiple light intensity values are measured over a field of view which includes at least a portion of the area illuminated by the light source. A computer processing system is used to identifying a portion of the light intensity values associated with a reflective surface and analyze the portion of the light intensity values to determine assessment for that reflective surface.

23 Claims, 19 Drawing Sheets



ZF EXHIBIT 1001

Related U.S. Application Data

application No. 12/419,843, filed on Apr. 7, 2009, now Pat. No. 7,995,796, which is a continuation of application No. 11/056,926, filed on Feb. 11, 2005, now Pat. No. 7,515,736, which is a continuation of application No. 09/928,218, filed on Aug. 10, 2001, now Pat. No. 6,891,960.

(60) Provisional application No. 60/224,761, filed on Aug. 12, 2000, provisional application No. 60/296,596, filed on Jun. 7, 2001.

(51) **Int. Cl.**

G08G 1/0967	(2006.01)
G01N 21/84	(2006.01)
G01S 17/06	(2006.01)

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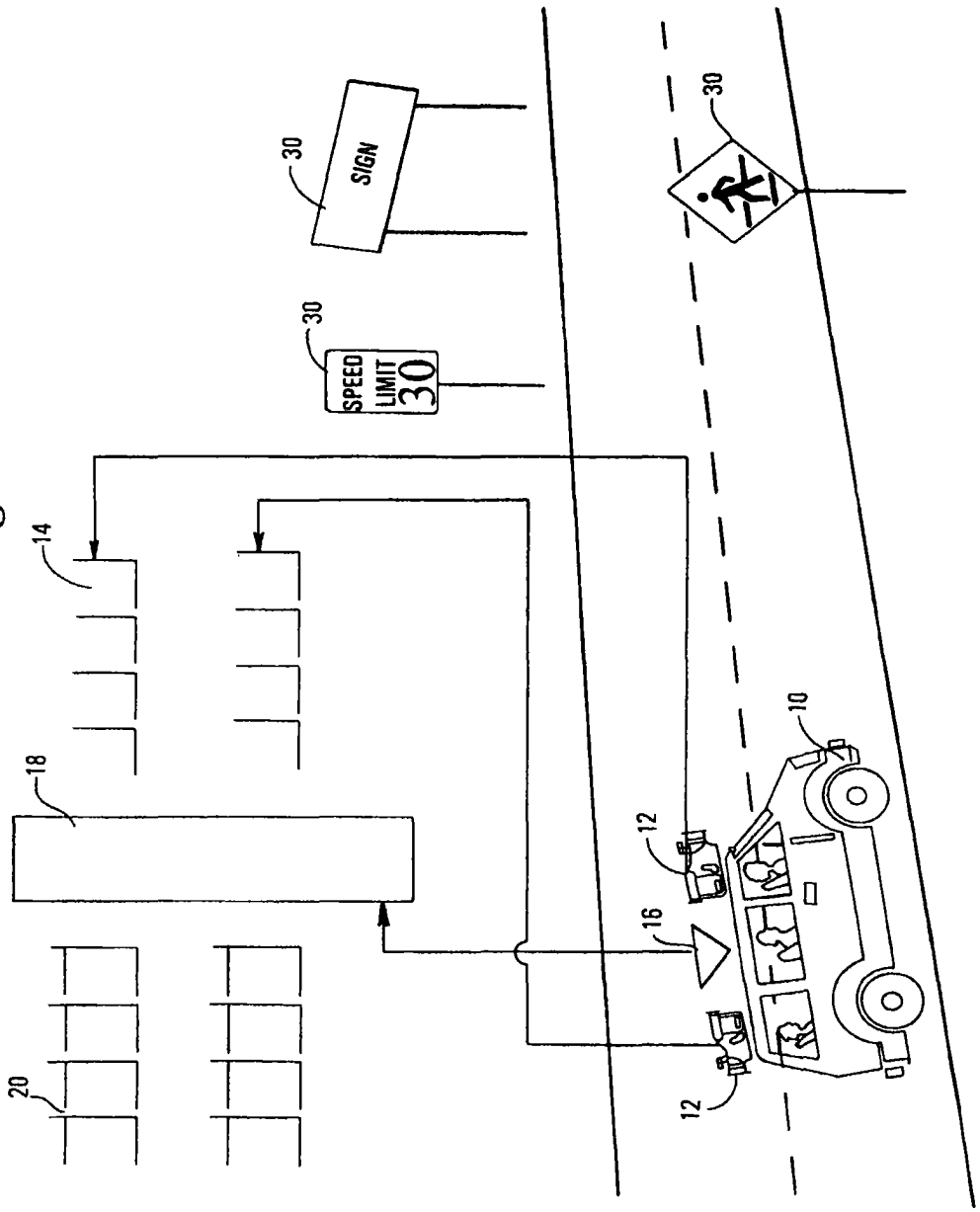

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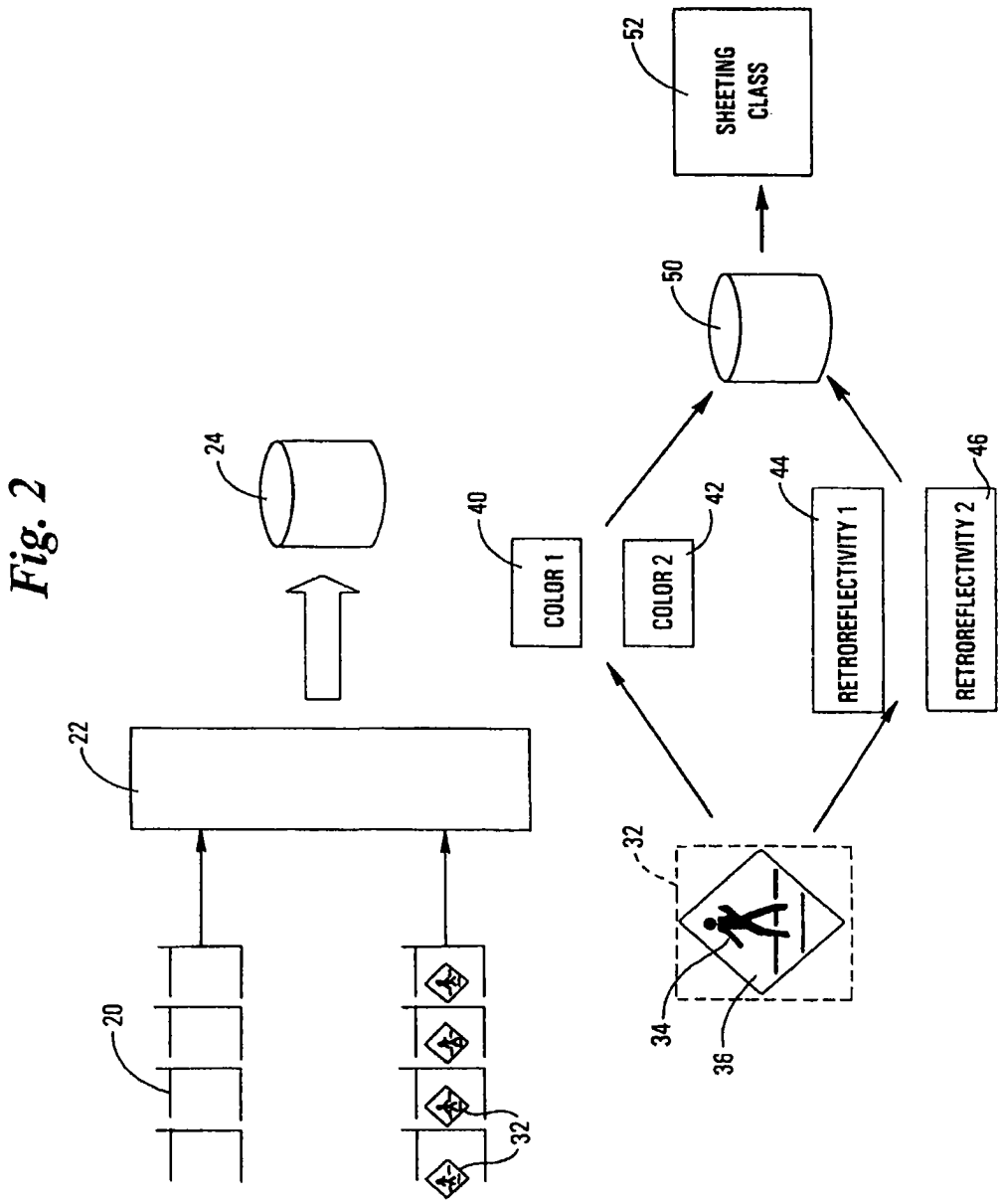
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22
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34
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COLOR 2
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RETROREFLECTIVITY 1
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RETROREFLECTIVITY 2
50
52
SHEETING CLASS

Fig. 2

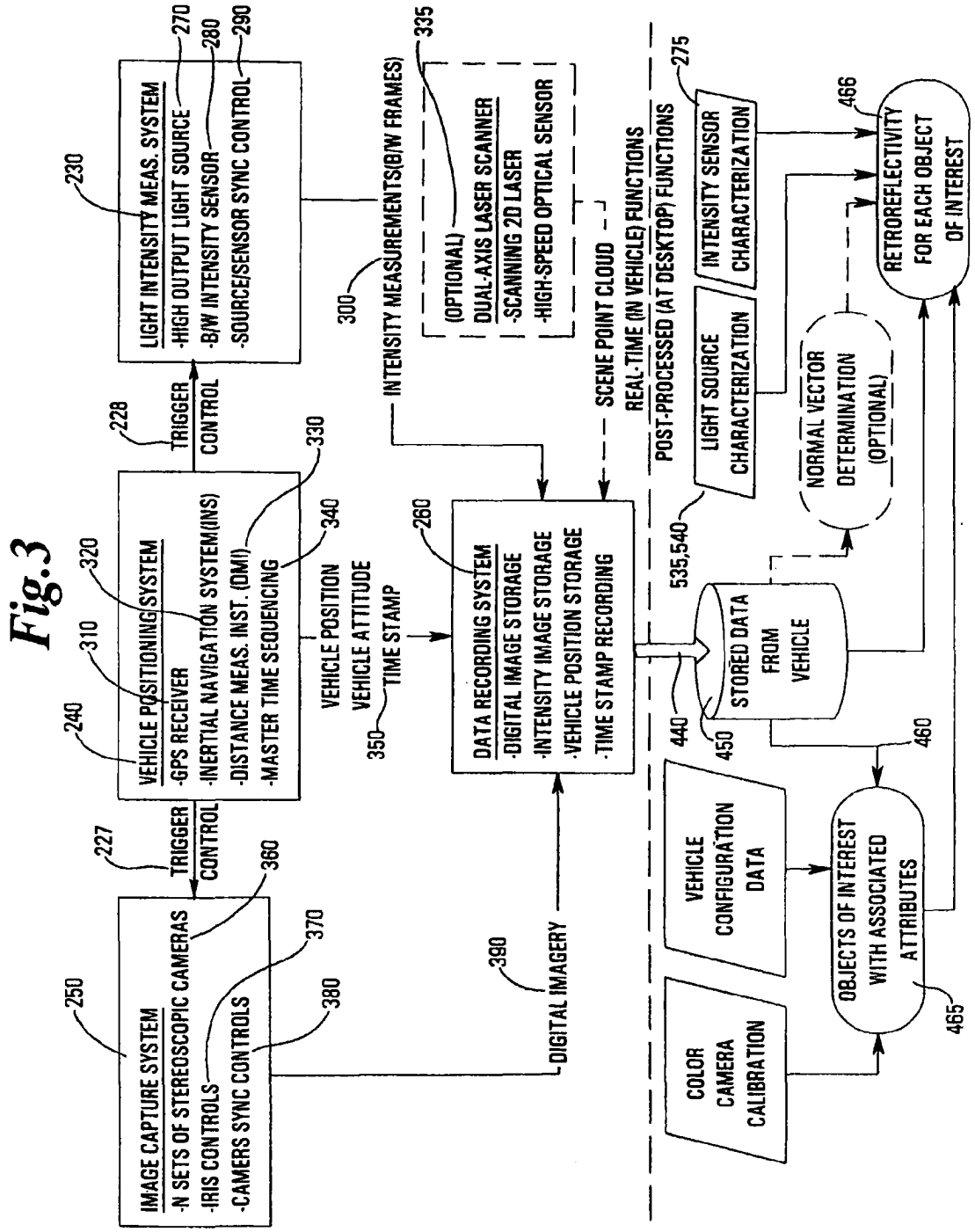
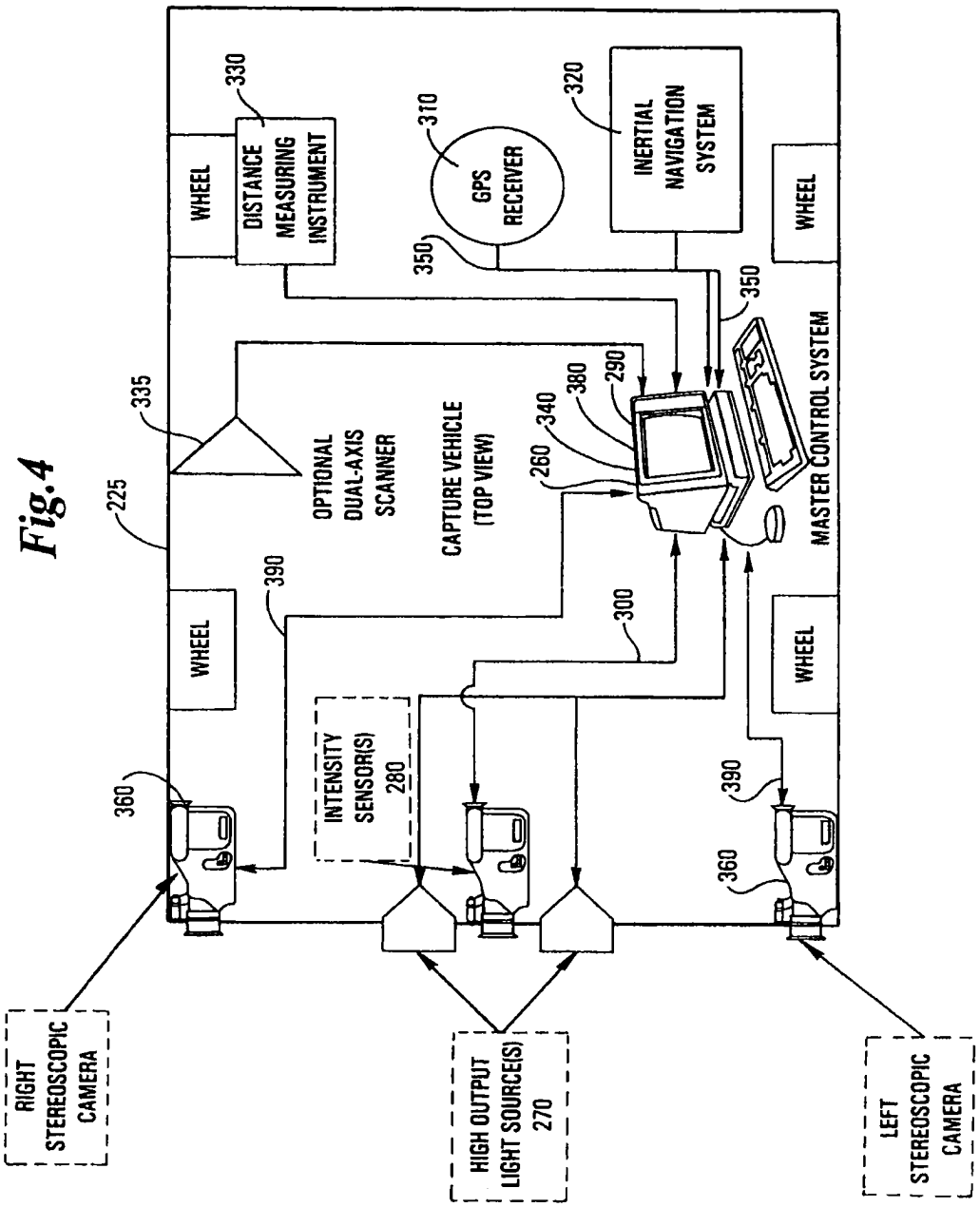


Fig.3
IMAGE CAPTURE SYSTEM
-N SETS OF STEREOSCOPIC CAMERAS
-IRIS CONTROLS
-CAMERS SYNC CONTROLS
250
360
370
380
227
TRIGGER
CONTROL
VEHICLE POSITIONING SYSTEM
-GPS RECEIVER
-INERTIAL NAVIGATION SYSTEM(INS)
-DISTANCE MEAS. INST. (DMI)
-MASTER TIME SEQUENCING
240
310
320
330
340
228
TRIGGER
CONTROL
LIGHT INTENSITY MEAS. SYSTEM
-HIGH OUTPUT LIGHT SOURCE
-B/W INTENSITY SENSOR
-SOURCE/SENSOR SYNC CONTROL
230
270
280
290
VEHICLE POSITION
VEHICLE ATTITUDE
TIME STAMP
350
DIGITAL IMAGERY
390
INTENSITY MEASUREMENTS(B/W FRAMES)
300
(OPTIONAL)
DUAL-AXIS LASER SCANNER
-SCANNING 2D LASER
-HIGH-SPEED OPTICAL SENSOR
335
DATA RECORDING SYSTEM
-DIGITAL IMAGE STORAGE
-INTENSITY IMAGE STORAGE
-VEHICLE POSITION STORAGE
-TIME STAMP RECORDING
260
SCENE POINT CLOUD
REAL-TIME (IN VEHICLE) FUNCTIONS
POST-PROCESSED (AT DESKTOP) FUNCTIONS
STORED DATA FROM VEHICLE
440
450
535,540
LIGHT SOURCE CHARACTERIZATION
INTENSITY SENSOR CHARACTERIZATION
275
NORMAL VECTOR DETERMINATION (OPTIONAL)
VEHICLE CONFIGURATION DATA
COLOR CAMERA CALIBRATION
OBJECTS OF INTEREST WITH ASSOCIATED ATTRIBUTES
460
465
RETROREFLECTIVITY FOR EACH OBJECT OF INTEREST
466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OPTIONAL DUAL-AXIS SCANNER
CAPTURE VEHICLE (TOP VIEW)
260
340
380
290
MASTER CONTROL SYSTEM
225
390
300
WHEEL
WHEEL
INTENSITY SENSOR(S) 280
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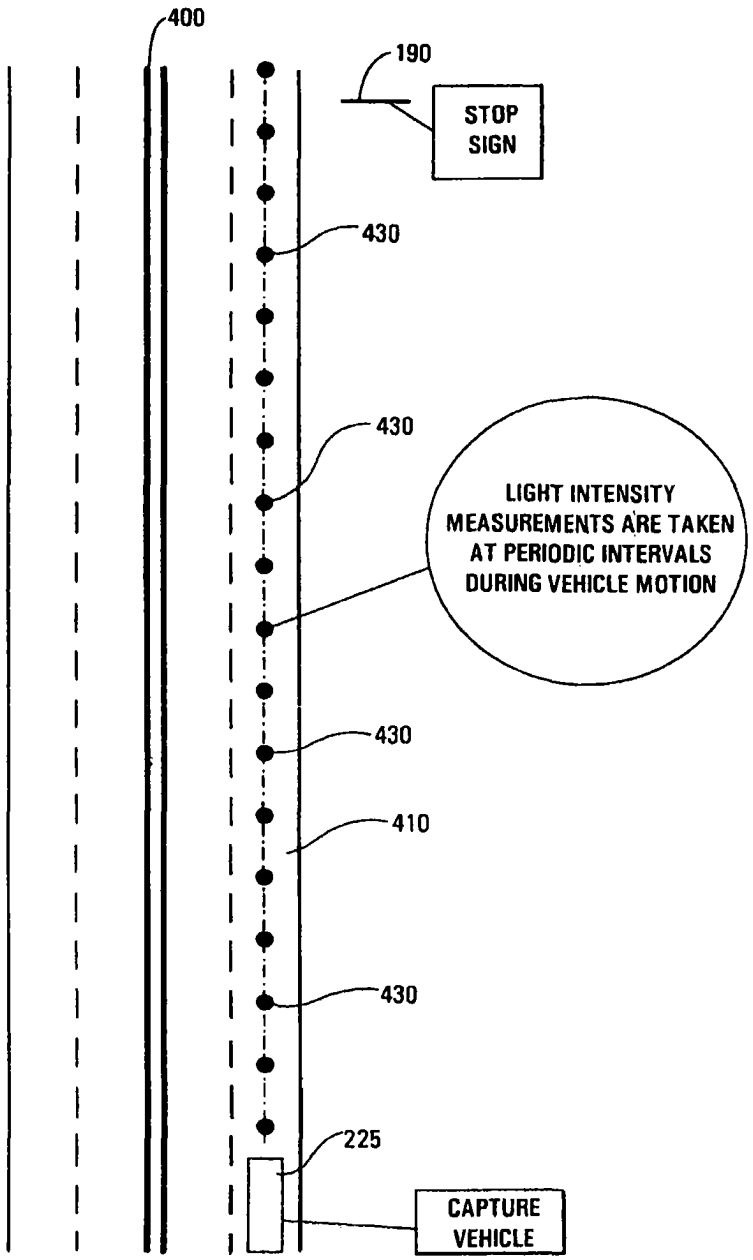
RIGHT STEREOSCOPIC CAMERA
HIGH OUTPUT LIGHT SOURCE(S) 270
LEFT STEREOSCOPIC CAMERA

Fig.4

Fig.5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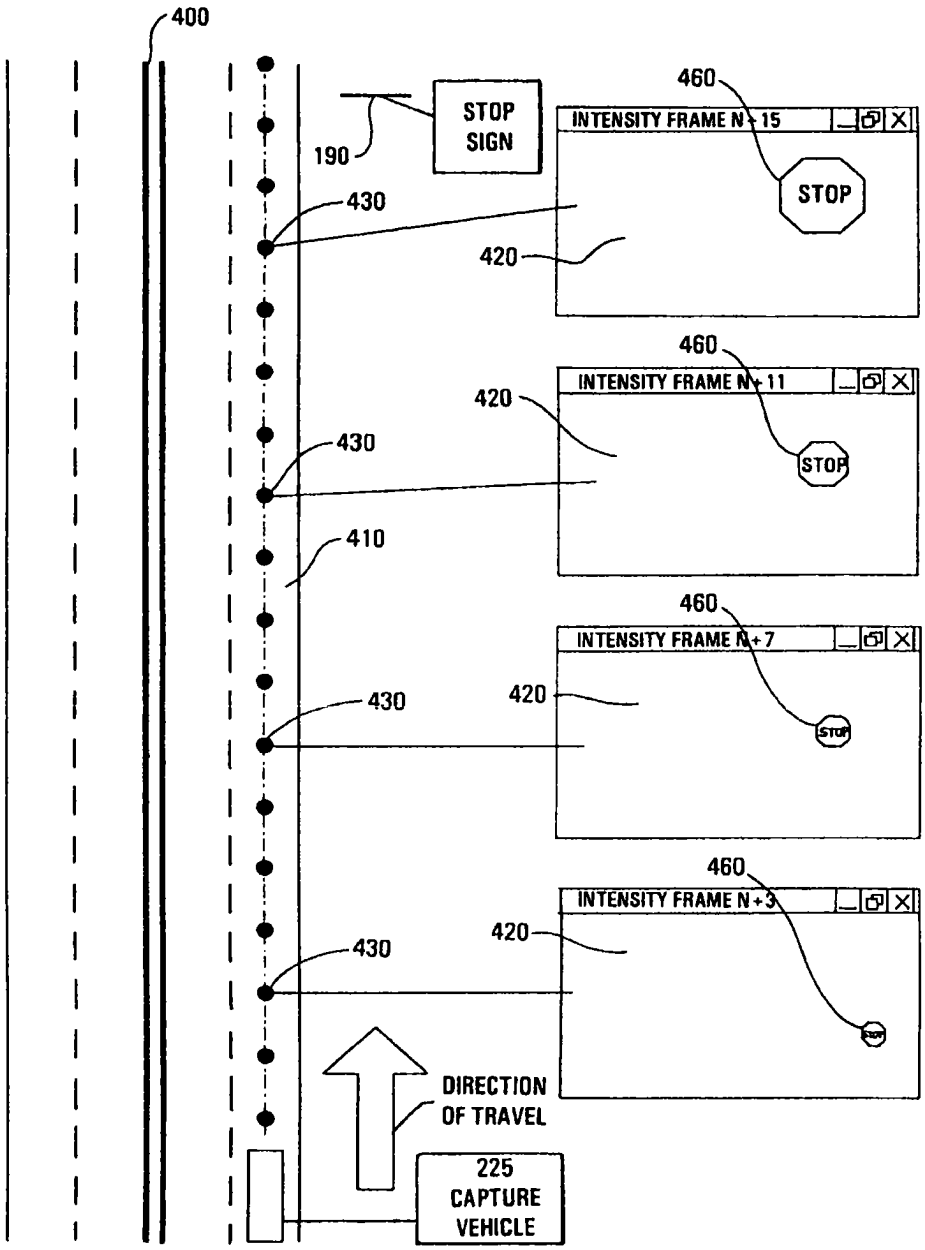
410
430
225
CAPTURE VEHICLE

Fig.6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STOP
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INTENSITY FRAME N+7
430
420
STOP
460
INTENSITY FRAME N+3
420
430
DIRECTION OF TRAVEL
225 CAPTURE VEHICLE

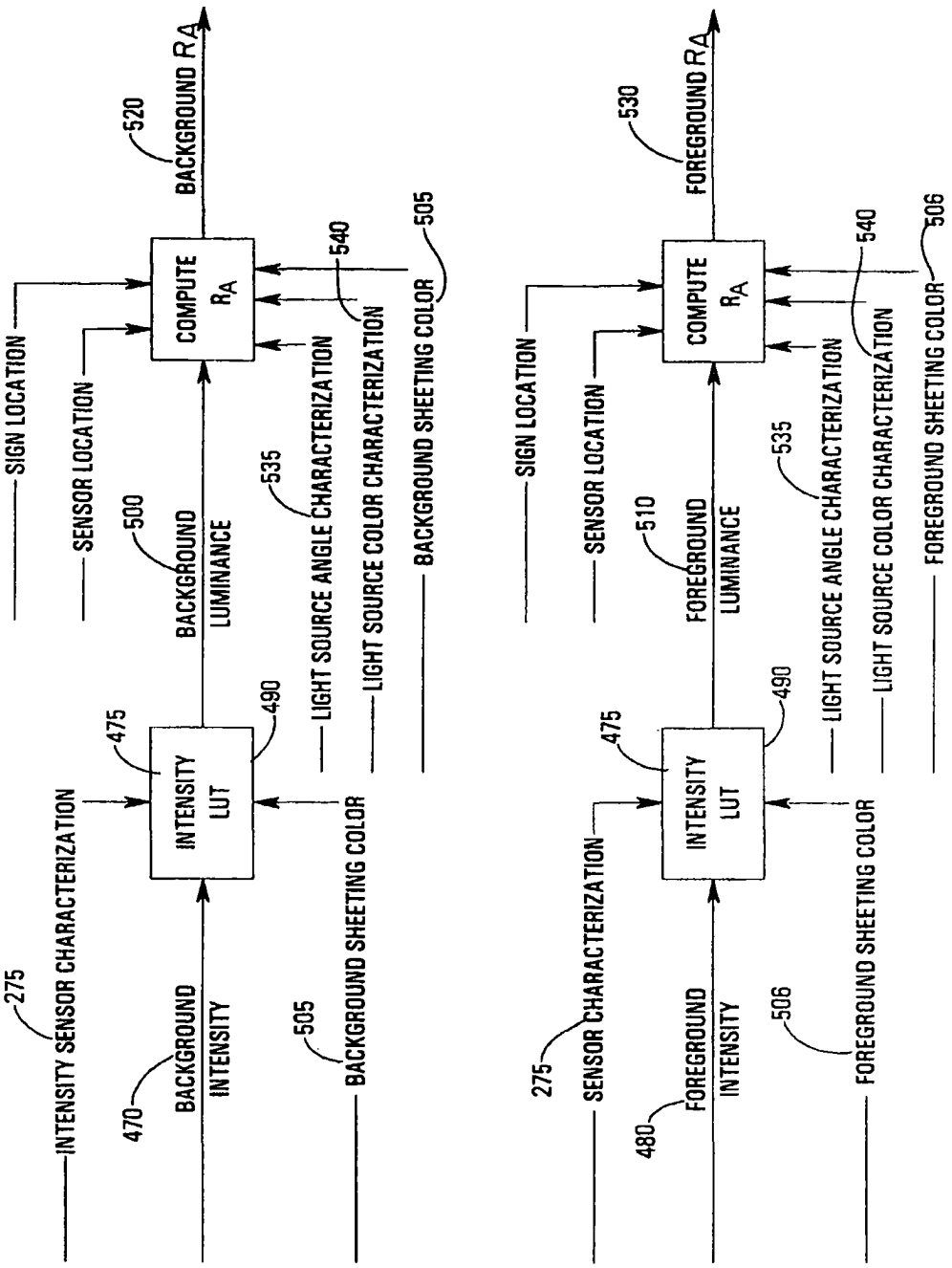

SIGN LOCATION
SENSOR LOCATION
INTENSITY SENSOR CHARACTERIZATION
275
BACKGROUND INTENSITY
470
INTENSITY LUT
475
BACKGROUND LUMINANCE
500
COMPUTE R_A
520
BACKGROUND R_A
LIGHT SOURCE ANGLE CHARACTERIZATION
535
LIGHT SOURCE COLOR CHARACTERIZATION
540
BACKGROUND SHEETING COLOR
505
490
BACKGROUND SHEETING COLOR
505
SIGN LOCATION
SENSOR LOCATION
SENSOR CHARACTERIZATION
275
FOREGROUND INTENSITY
480
INTENSITY LUT
475
FOREGROUND LUMINANCE
510
COMPUTE R_A
530
FOREGROUND R_A
LIGHT SOURCE ANGLE CHARACTERIZATION
535
LIGHT SOURCE COLOR CHARACTERIZATION
540
FOREGROUND SHEETING COLOR
506
490
FOREGROUND SHEETING COLOR
506

Fig. 7

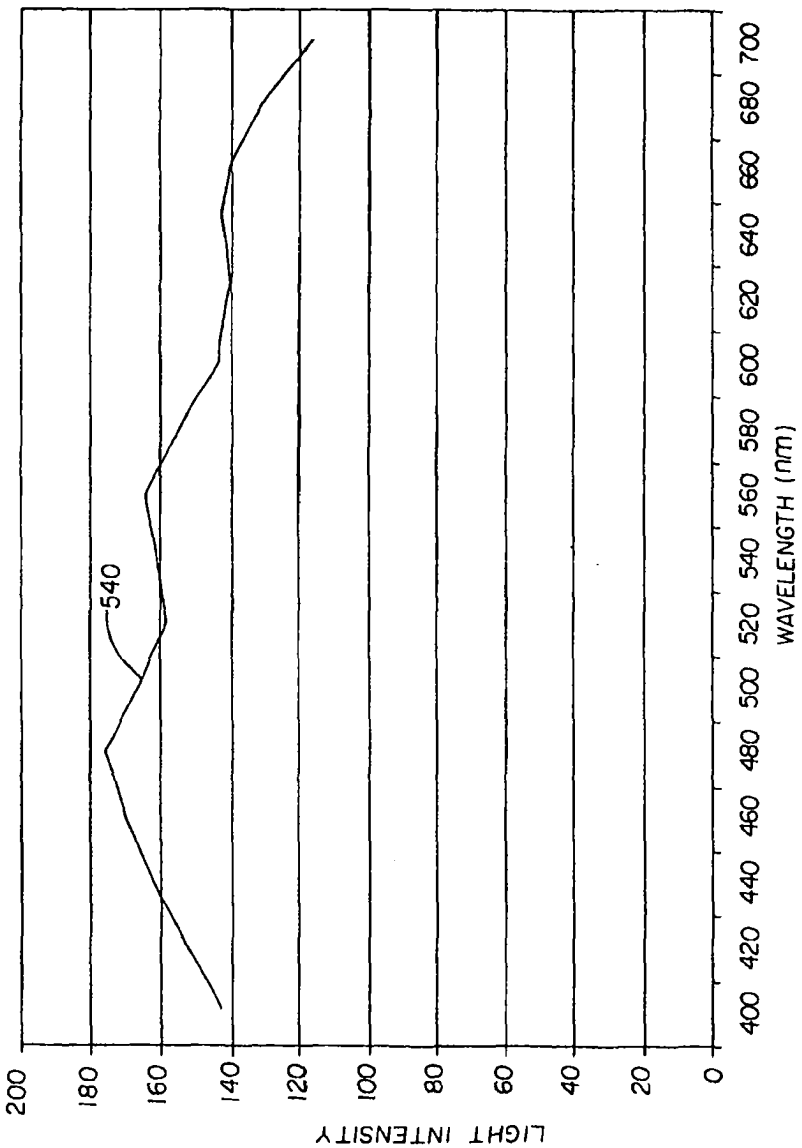

540
LIGHT INTENSITY
200
180
160
140
120
100
80
60
40
20
0
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
WAVELENGTH (nm)

Fig. 8

Fig.9

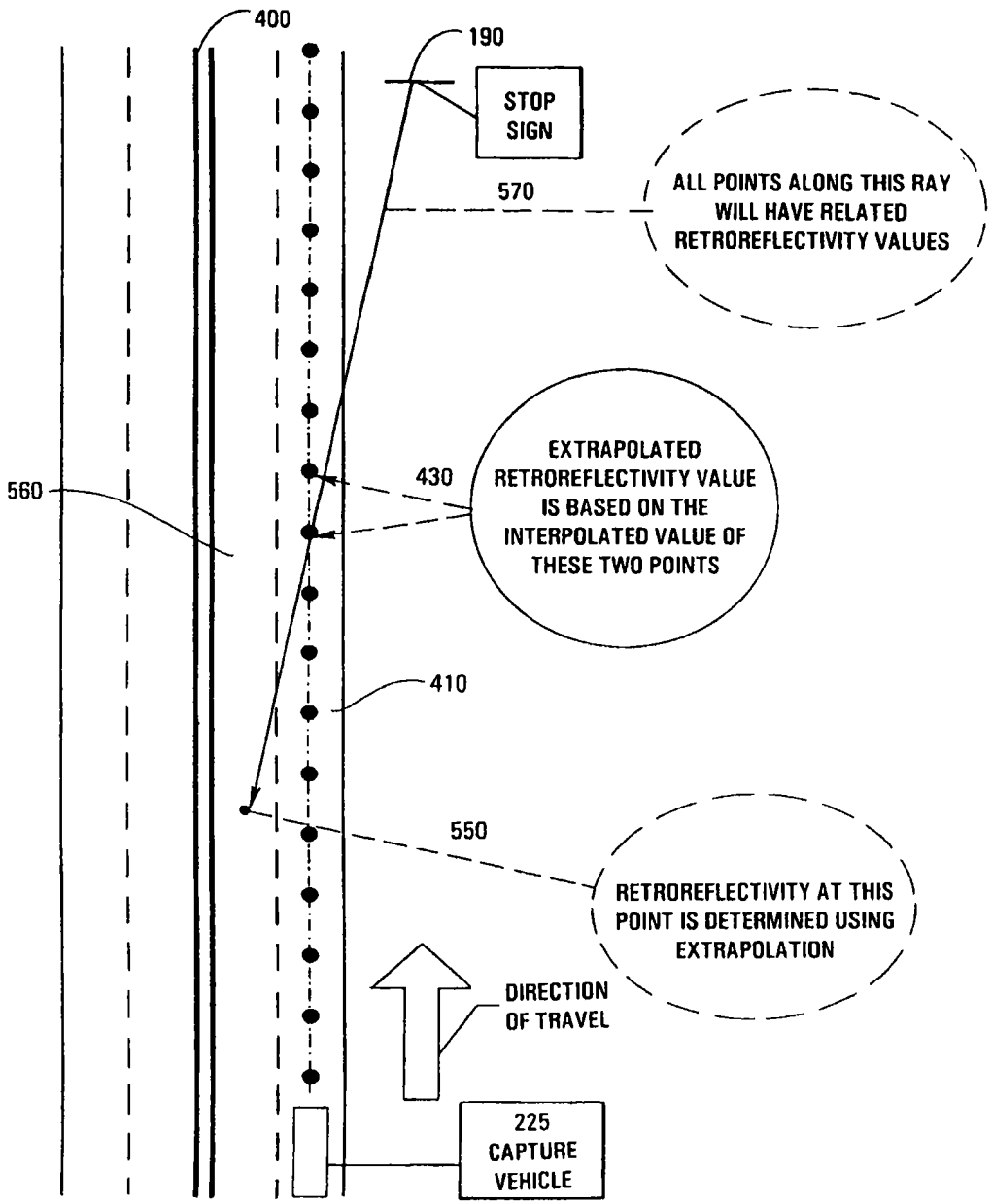
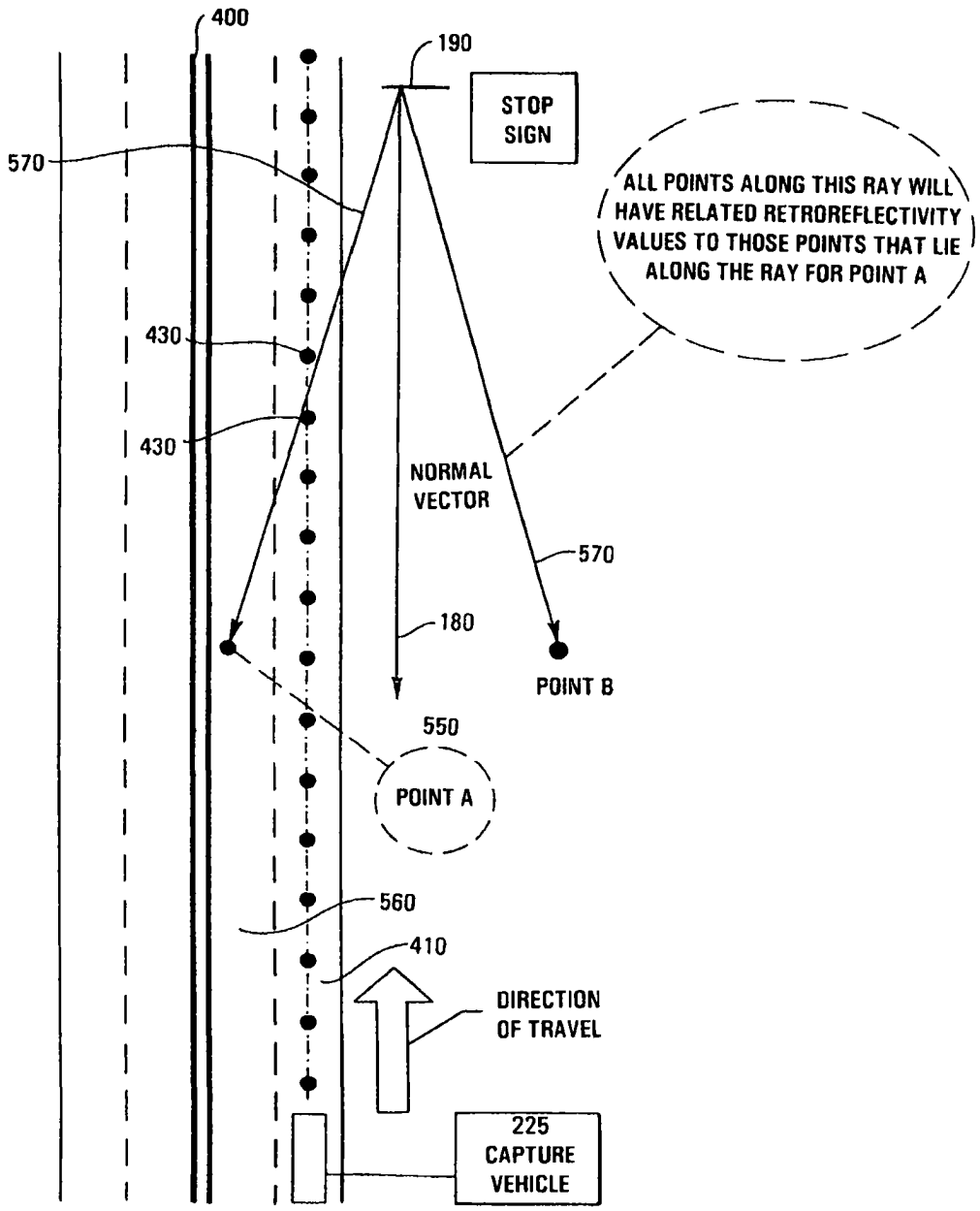

400
190
STOP SIGN
570
ALL POINTS ALONG THIS RAY WILL HAVE RELATED RETROREFLECTIVITY VALUES
560
430
EXTRAPOLATED RETROREFLECTIVITY VALUE IS BASED ON THE INTERPOLATED VALUE OF THESE TWO POINTS
410
550
RETROREFLECTIVITY AT THIS POINT IS DETERMINED USING EXTRAPOLATION
DIRECTION OF TRAVEL
225 CAPTURE VEHICLE

Fig.10


400
190
STOP SIGN
570
ALL POINTS ALONG THIS RAY WILL HAVE RELATED RETROREFLECTIVITY VALUES TO THOSE POINTS THAT LIE ALONG THE RAY FOR POINT A
430
430
NORMAL VECTOR
570
180
POINT B
550
POINT A
560
410
DIRECTION OF TRAVEL
225 CAPTURE VEHICLE

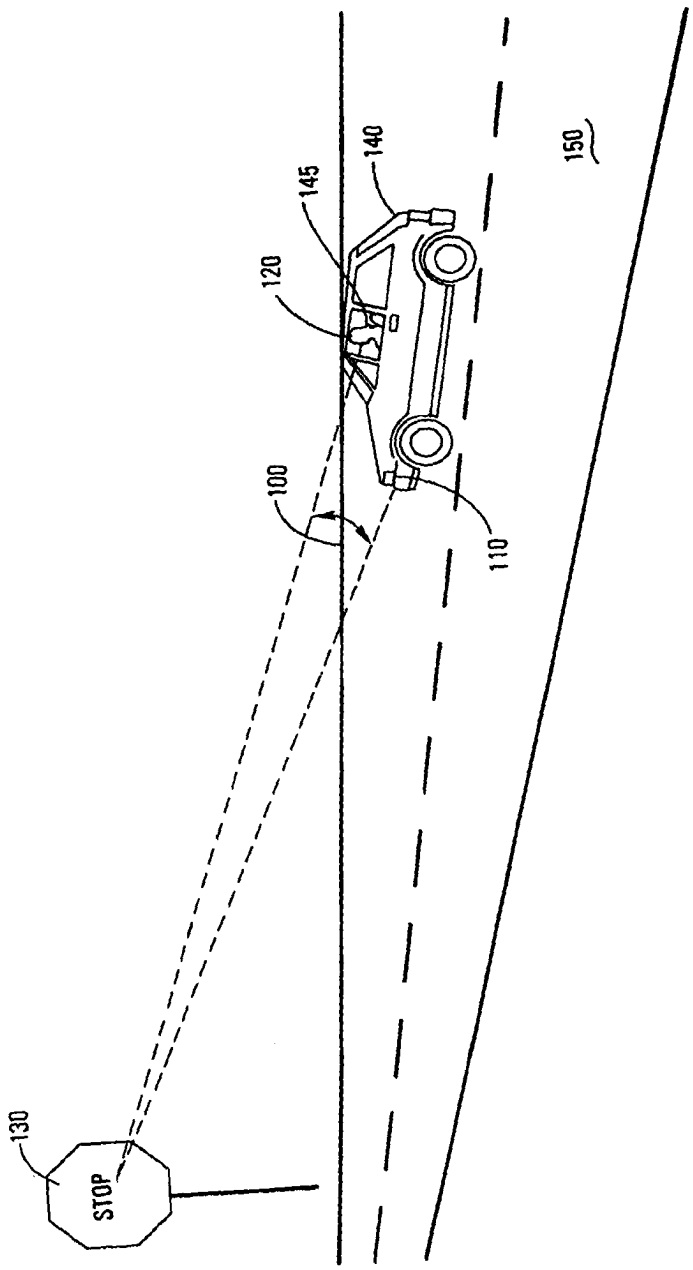


Fig. 11

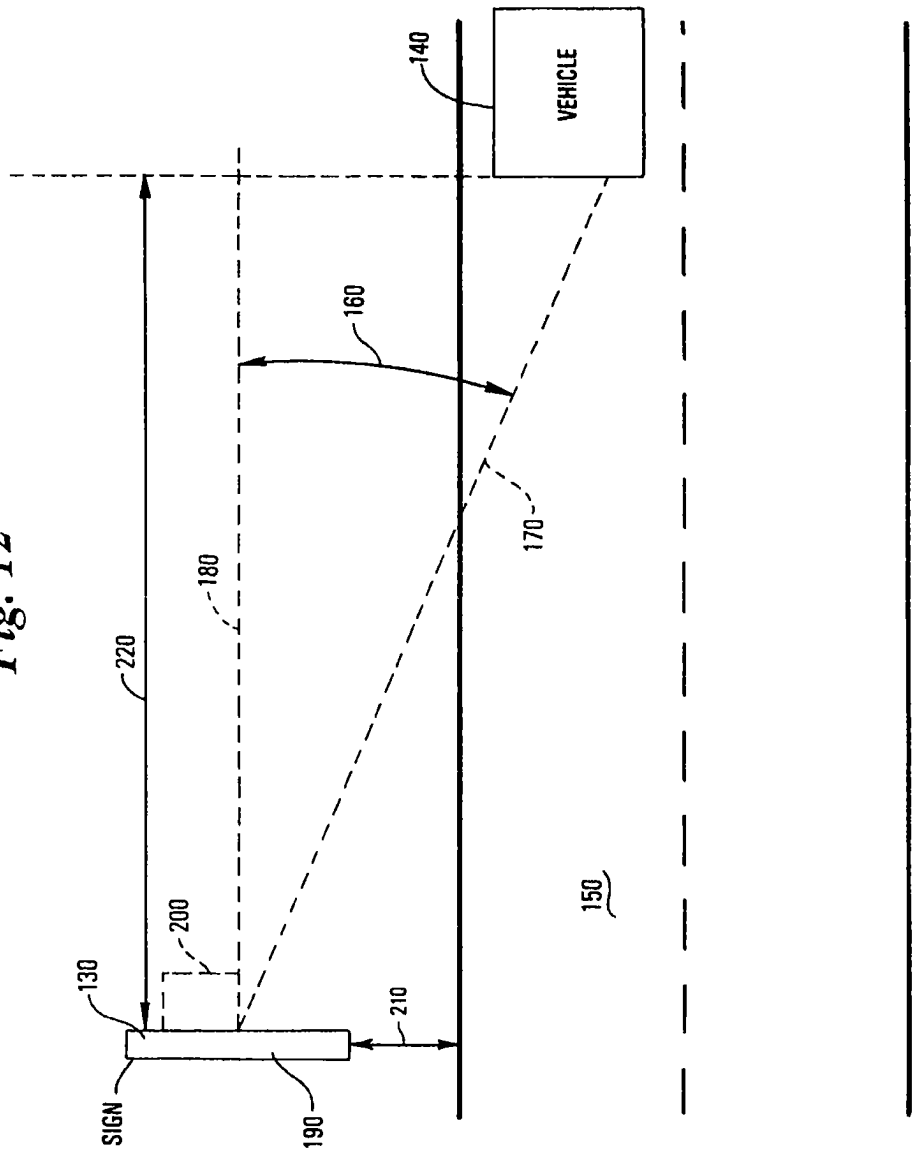


Fig. 12

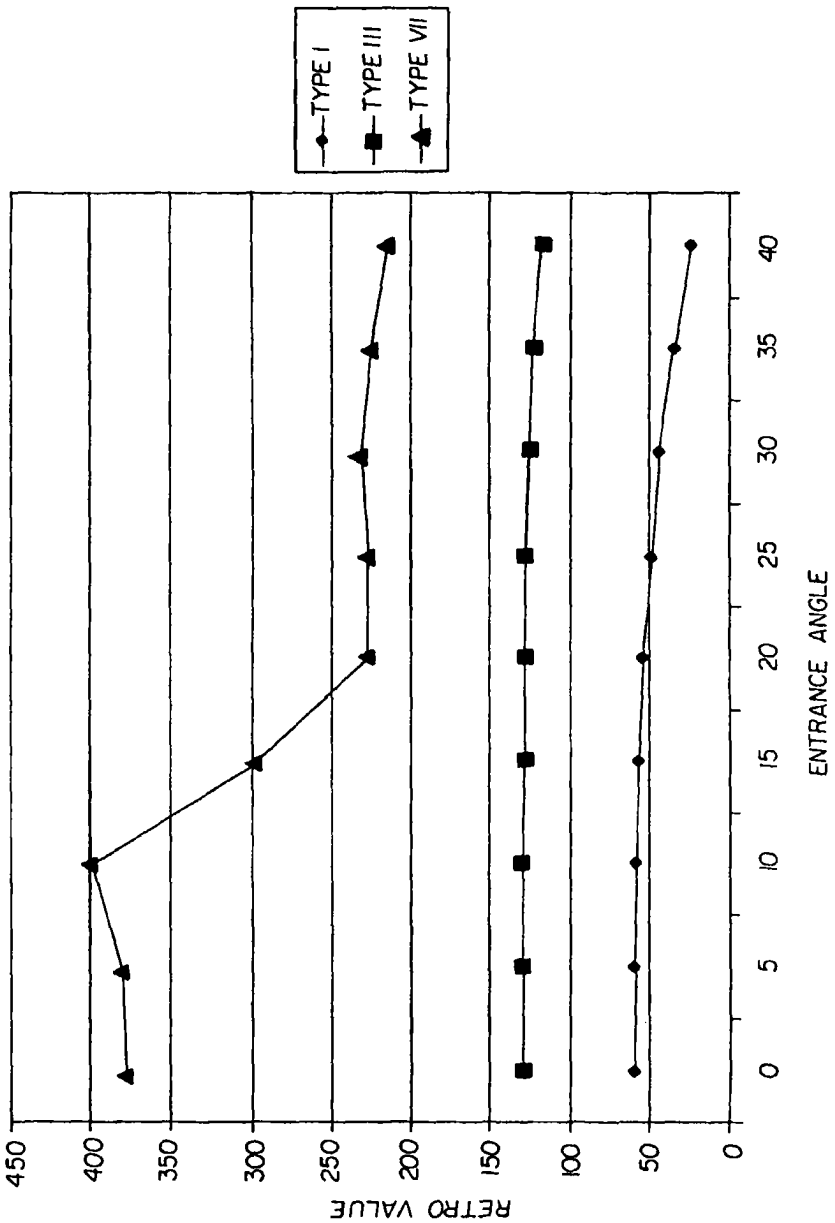

TYPE I
TYPE III
TYPE VII
RETRO VALUE
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
ENTRANCE ANGLE

Fig. 13

Fig.14A

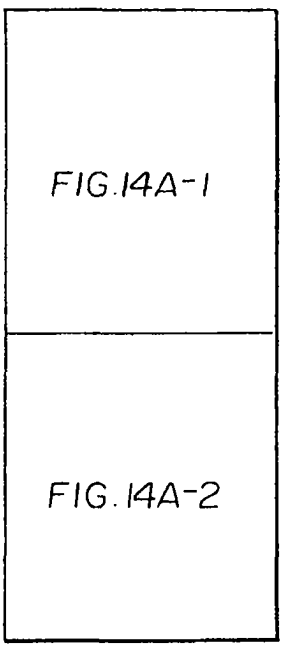


Fig.14B

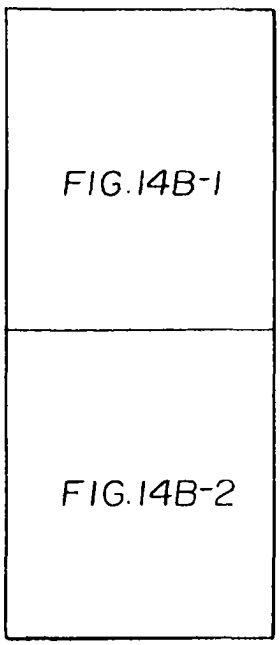


Fig.14A-1

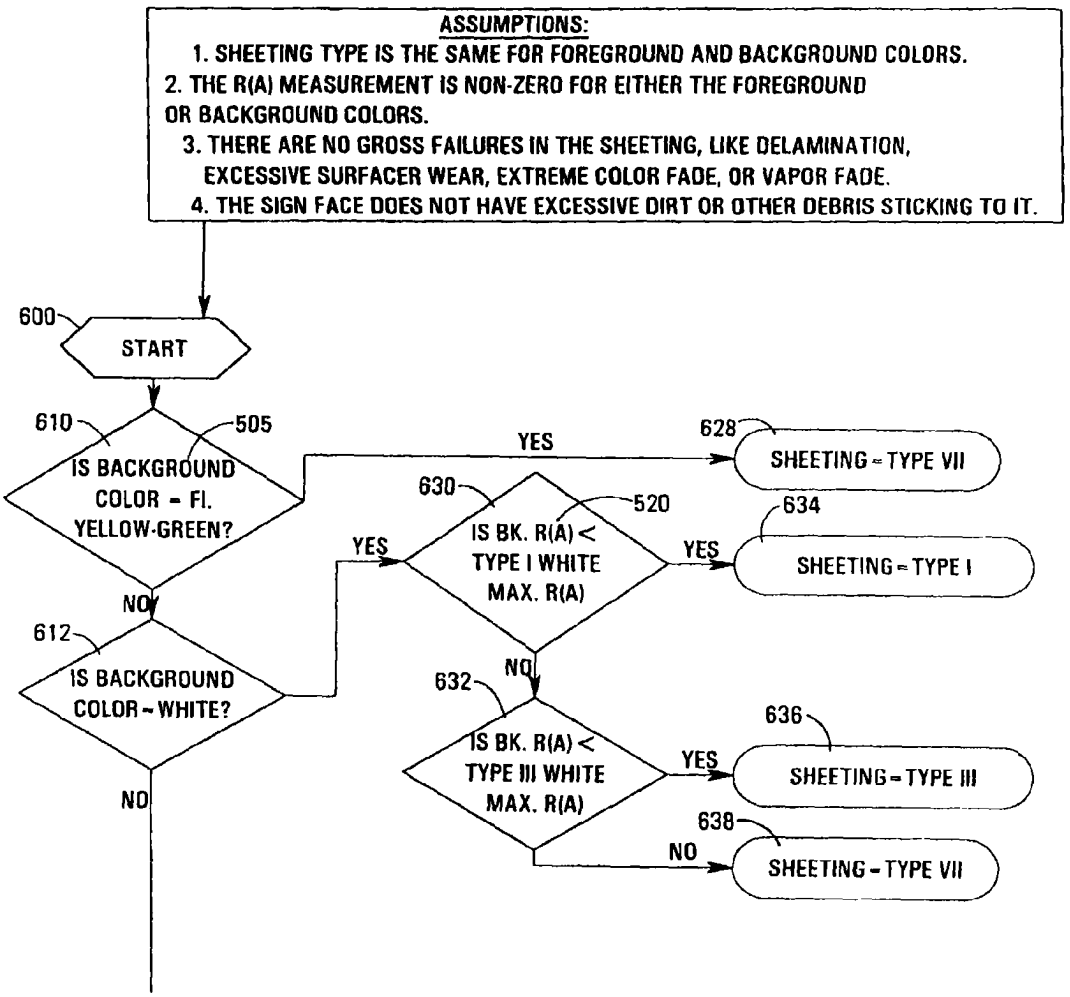

ASSUMPTIONS:
1. SHEETING TYPE IS THE SAME FOR FOREGROUND AND BACKGROUND COLORS.
2. THE R(A) MEASUREMENT IS NON-ZERO FOR EITHER THE FOREGROUND OR BACKGROUND COLORS.
3. THERE ARE NO GROSS FAILURES IN THE SHEETING, LIKE DELAMINATION, EXCESSIVE SURFACER WEAR, EXTREME COLOR FADE, OR VAPOR FADE.
4. THE SIGN FACE DOES NOT HAVE EXCESSIVE DIRT OR OTHER DEBRIS STICKING TO IT.
600
START
610
505
IS BACKGROUND COLOR = Fl. YELLOW-GREEN?
YES
628
SHEETING = TYPE VII
NO
612
IS BACKGROUND COLOR = WHITE?
YES
630
520
IS BK. R(A) < TYPE I WHITE MAX. R(A)
YES
634
SHEETING = TYPE I
NO
632
IS BK. R(A) < TYPE III WHITE MAX. R(A)
YES
636
SHEETING = TYPE III
NO
638
SHEETING = TYPE VII
NO

Fig.14A-2

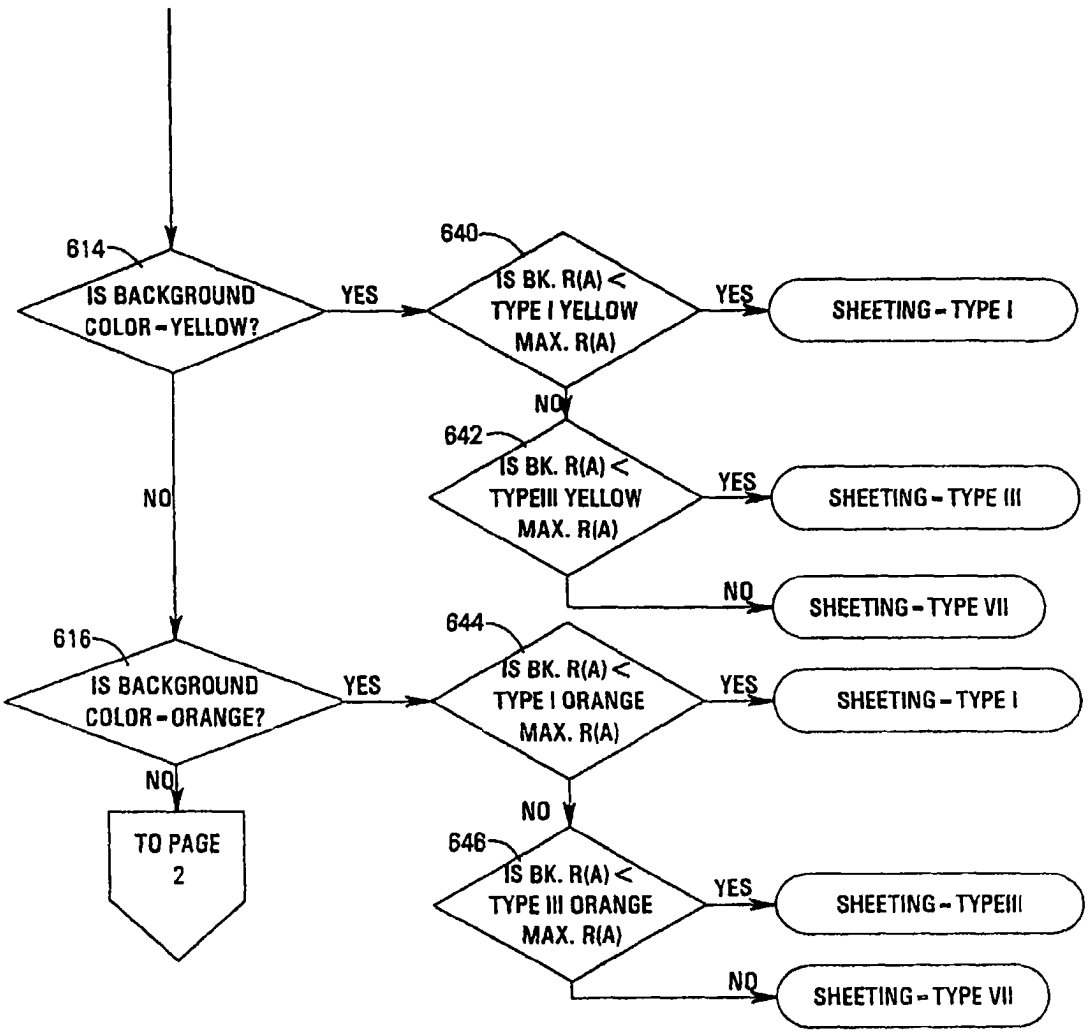

614
IS BACKGROUND COLOR = YELLOW?
YES
640
IS BK. R(A) < TYPE I YELLOW MAX. R(A)
YES
SHEETING - TYPE I
NO
642
IS BK. R(A) < TYPEIII YELLOW MAX. R(A)
YES
SHEETING - TYPE III
NO
SHEETING - TYPE VII
NO
616
IS BACKGROUND COLOR = ORANGE?
YES
644
IS BK. R(A) < TYPE I ORANGE MAX. R(A)
YES
SHEETING - TYPE I
NO
TO PAGE 2
NO
646
IS BK. R(A) < TYPE III ORANGE MAX. R(A)
YES
SHEETING - TYPEIII
NO
SHEETING - TYPE VII

Fig.14B-1

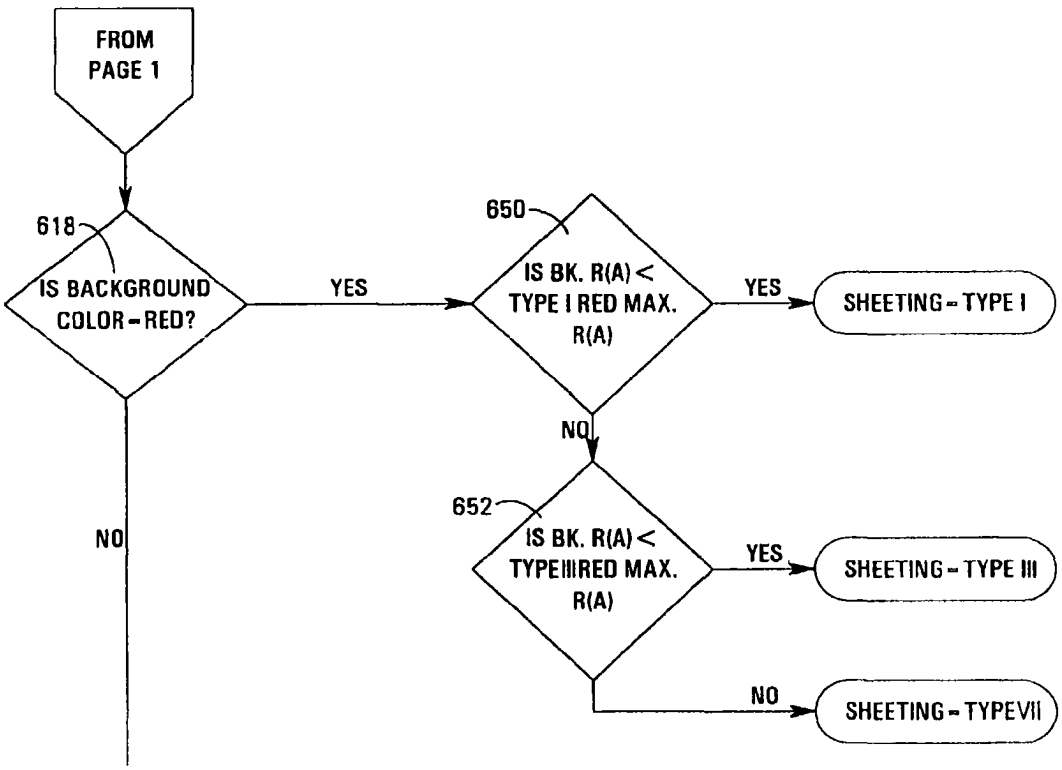

FROM
PAGE 1
618
IS BACKGROUND
COLOR = RED?
YES
NO
650
IS BK. R(A) <
TYPE I RED MAX.
R(A)
YES
SHEETING = TYPE I
NO
652
IS BK. R(A) <
TYPE III RED MAX.
R(A)
YES
SHEETING = TYPE III
NO
SHEETING = TYPE VII

Fig.14B-2

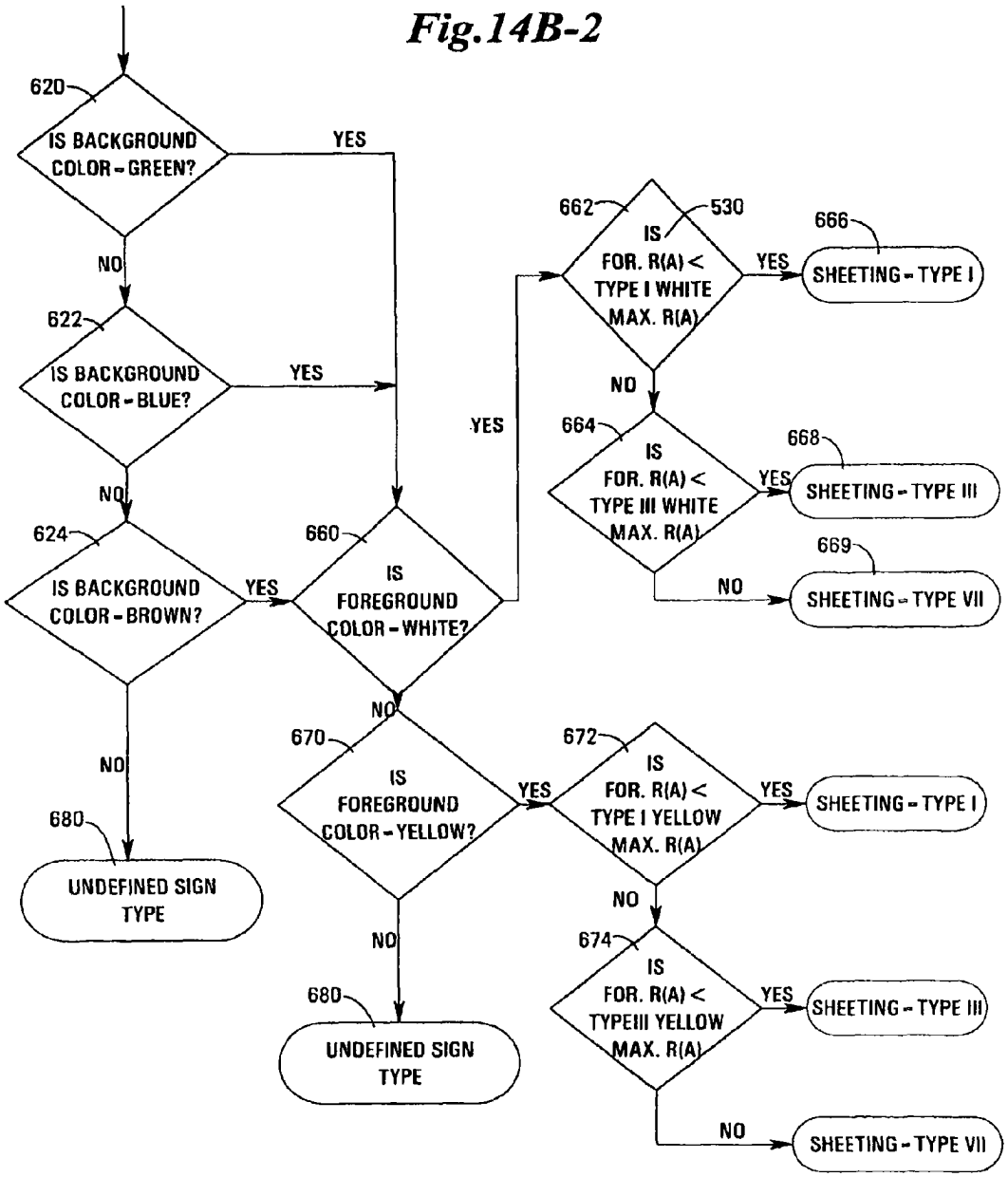
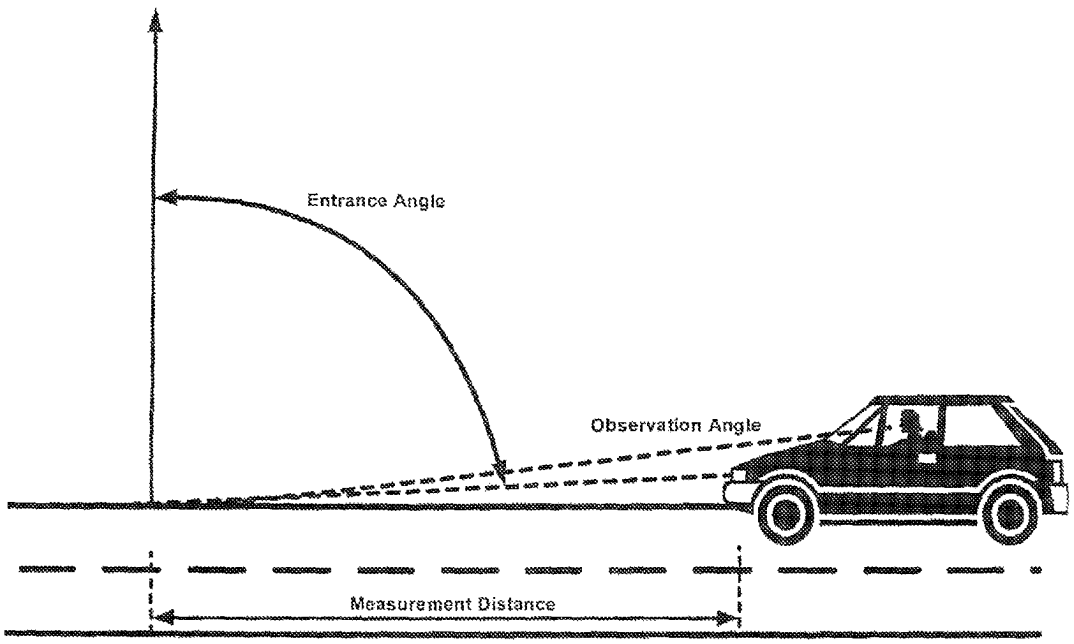

620
IS BACKGROUND COLOR - GREEN?
YES
NO
622
IS BACKGROUND COLOR - BLUE?
YES
NO
624
IS BACKGROUND COLOR - BROWN?
YES
NO
680
UNDEFINED SIGN TYPE
660
IS FOREGROUND COLOR - WHITE?
YES
NO
662
530
IS FOR. R(A) < TYPE I WHITE MAX. R(A)
YES
666
SHEETING - TYPE I
NO
664
IS FOR. R(A) < TYPE III WHITE MAX. R(A)
YES
668
SHEETING - TYPE III
NO
669
SHEETING - TYPE VII
670
IS FOREGROUND COLOR - YELLOW?
YES
NO
680
UNDEFINED SIGN TYPE
672
IS FOR. R(A) < TYPE I YELLOW MAX. R(A)
YES
SHEETING - TYPE I
NO
674
IS FOR. R(A) < TYPEIII YELLOW MAX. R(A)
YES
SHEETING - TYPE III
NO
SHEETING - TYPE VII

FIG. 15 Pavement Marking Geometry



SYSTEM AND ASSESSMENT OF REFLECTIVE OBJECTS ALONG A ROADWAY

RELATED APPLICATIONS

The present application is a continuation of U.S. application Ser. No. 14/025,614, filed Sep. 12, 2013, now U.S. Pat. No. 8,860,944, which is a divisional of U.S. application Ser. No. 13/205,337, filed Aug. 8, 2011, now U.S. Pat. No. 8,660,311, which is a divisional of U.S. application Ser. No. 12/419,843, filed Apr. 7, 2009, now U.S. Pat. No. 7,995,796, which is a continuation of application Ser. No. 11/056,926, filed Feb. 11, 2005, now U.S. Pat. No. 7,515,736, which is a continuation of application Ser. No. 09/928,218, filed Aug. 10, 2001, now U.S. Pat. No. 6,891,960, which claims the benefit of the contents and filing date accorded to two U.S. Provisional Patent Applications, the first of which was filed on Aug. 12, 2000, as Application No. 60/224,761, and the second of which was filed on Jun. 7, 2001, as Application No. 60/296,596. The application is related to U.S. Pat. No. 6,674,878, issued Jan. 6, 2004, and U.S. Pat. No. 6,453,056, issued Sep. 17, 2002, which is a continuation of U.S. Pat. No. 6,266,442, filed Oct. 23, 1998, all of which are hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates generally to the field of automated object recognition. More specifically, the present invention relates to a system for classifying different types of sheeting materials of road signs depicted in a videostream.

BACKGROUND OF THE INVENTION

The goal of using an automated image identification system to recognize road signs and traffic signs is well known. Various techniques have been proposed for the recognition of road signs as part of a real-time automated vehicle navigation system. Due to the processing limitations imposed by a real-time environment, almost all of these techniques have involved template matching of shape and color. Given the wide variations in lighting and conditions, few if any of these systems provide accurate results.

Another use of automated road sign recognition is for the purpose of identifying and creating an accurate inventory of all road signs and traffic signs along a given street or highway. In one system as described in U.S. Pat. No. 6,266,442, entitled, "METHOD AND APPARATUS FOR IDENTIFYING OBJECTS DEPICTED IN A VIDEOSTREAM," issued Jul. 24, 2001 to Laumeyer et al., an acquisition vehicle equipped with video cameras and position identifying technology, such as global positioning satellite (GPS) receivers, is systematically driven over the roads and streets in a given area to produce a videostream tagged with location information. The tagged videostream is analyzed by computer software routines to perform object recognition of the desired objects, the road signs in this case. The results of this analysis are exported to an asset management database that stores attributes of the road signs.

Road signs are manufactured from a sheeting material made up of multiple layered films (one or more colored layers that are fused with a layer that produces the reflectivity) that is adhered to the sign face. There are different types of sheeting material utilized in the road sign industry. Currently, specific attributes about each road sign like retroreflectivity (measured in candelas/lux/sq. meter) and sheeting type must

be gathered manually by sending personnel in the field to measure retroreflectivity with a handheld device (like the Impulse RM retro-reflectometer from Laser Technology, Inc.) and to visually determine the sheeting type of each sign. Measurements of retroreflectivity and identification of sheeting type are helpful in evaluating the visibility of a sign and whether it has deteriorated due to a breakdown in the pigments or reflective material in the sheeting material of the sign. The retroreflectivity and sheeting type can also be used to produce a predictive model of how the sign will perform into the future based on the as-measured characteristics.

Generally, highway and street maintenance departments do not systematically evaluate the deterioration of the reflective materials used on road signs and markers. If inspections of road signs or markers are performed, they are typically accomplished by having inspectors manually position a handheld retroreflectometer directly on the surface of a sign in order to determine a retroreflectivity value for that sign. When there are a large number of road signs or markers (sometimes referred to as traffic control devices or TCDs) in a given jurisdiction, the task of manually inspecting all of these road signs and markers can be time consuming and expensive.

One technique for determining retroreflectivity, designated as "R_A" generally (and from time to time in this disclosure), which does not require that a retroreflectometer be placed directly on a sign is described in U.S. Pat. No. 6,212,480 entitled, "APPARATUS AND METHOD FOR DETERMINING PRECISION REFLECTIVITY OF HIGHWAY SIGNS AND OTHER REFLECTIVE OBJECTS UTILIZING AN OPTICAL RANGE FINDER INSTRUMENT" issued Apr. 3, 2001 to Dunne. The Dunne patent relates to a device commercialized by the assignee thereof and marketed as the "Impulse RM" retro-reflectometer by Laser Technology, Inc., of Englewood, Colo., USA. In use, handheld devices fabricated according to the Dunne patent are manually directed toward, or precisely at, a target object and then manually "fired." Once fired, the handheld device bounces a laser off the target object and measures the reflected laser energy that is then used to determine a retroreflectivity.

There are several drawbacks of the handheld laser arrangement described by the Dunne patent. The handheld device can only measure a single color at a time and can only measure one object at a time. The determination of retroreflectivity for a given object is valid only for the actual location, or discrete measurement point, along the roadway at which the measurement was made by the human operator. In order to validate a measurement made by such devices, the device must be taken back to the precise location in the field where an original measurement occurred for a valid comparison measurement to be made.

Another technique established for determining the retroreflectivity of signs has been introduced by the Federal Highway Administration (FHWA). The Sign Management and Retroreflectivity Tracking System (SMARTS) is a vehicle that contains one high intensity flash source (similar to the Honeywell StrobeGuard™ SG-60 device), one color camera, two black and white cameras, and a range-sensing device. The SMARTS vehicle requires two people for proper operation—one driver and one system operator to point the device at the target sign and arm the system. The SMARTS travels down the road, and the system operator "locks on" to a sign up ahead by rotating the camera and light assembly to point at the sign. At a distance of 60 meters, the system triggers the flash source to illuminate the sign surface, an image of which is captured by one of the black and white cameras. A histogram is produced of the sign's legend and background that is then

used to calculate retroreflectivity. A GPS system stores the location of the vehicle along with the calculated retroreflectivity in a computer database.

Like the handheld laser device of the Dunne patent, the SMARTS device can only determine retroreflectivity for one sign at a time and can only determine retroreflectivity for the discrete point on the roadway 60 meters from the sign. Two people are required to operate the vehicle and measurement system. The SMARTS vehicle cannot make retroreflectivity determinations for signs on both sides of the roadway in a single pass over the roadway, and does not produce nighttime sign visibility information for lanes on the roadway not traveled by the vehicle. Because the system operator in the SMARTS vehicle must locate and track signs to be measured while the vehicle is in motion, a high level of operational skill is required and the likelihood that a sign will be missed is significant. Most importantly for purposes of the present invention, the SMARTS device makes no attempt to automatically determine sheeting type of a sign.

There are an estimated 58 million individual TCDs that must be monitored and maintained in the United States and new TCD installations increase this number daily. For the reasons that have been described, the existing techniques for determining retroreflectivity do not lend themselves to increasing processing throughput so as to more easily manage the monitoring and maintenance of these TCDs. So called automated data collection systems often require that normal traffic be stopped during data collection because either the acquisition vehicle moved very slowly or because the acquisition vehicle had to come to a full stop before recording data about the roadside scene. Furthermore, a human operator is required to point one or more measurement devices at a sign of interest, perform data collection for that particular sign and then set up the device for another particular sign of interest. With such a large number of TCDs that must be monitored, it would be desirable to provide an automated system for determining the retroreflectivity of road signs and markers that addresses these and other shortcomings of the existing techniques to enable a higher processing throughput of an automated determination of the retroreflectivity and sheeting classification of road signs and markers.

SUMMARY OF THE INVENTION

The present invention is a system for classifying different types of sheeting materials of road signs depicted in a videostream. Once a road sign has been identified in the videostream, the frames associated with that road sign are analyzed to determine each of a plurality of colors present on the road sign. An estimated retroreflectivity for each of the plurality of colors present on the road sign is then determined. By comparing the estimated retroreflectivity for each of the plurality of colors against known minimum retroreflectivity values for the corresponding color for different types of sheeting materials, an accurate determination of the classification of the sheeting material of the road sign is established. Preferably, certain conditions of gross failure of the sheeting material are filtered out before classification of the sheeting material is determined.

In a preferred embodiment, a system for the automated determination of retroreflectivity values for reflective surfaces disposed along a roadway is utilized to establish the retroreflectivity values for both foreground and background colors of a road sign for the purpose of classifying the sheeting material of that sign. An area along the roadway that includes at least one reflective surface is repeatedly illuminated by a light source and multiple light intensity values are measured over a field of view which includes at least a portion of the area illuminated by the light source. A computer processing system is used to identify a portion of the light intensity values associated with a reflective surface and analyze the portion of the light intensity values to determine at least one retroreflectivity value for that reflective surface. Color images of the area and locational information are also generated by the system and are used together with a characterization profile of the light source to enhance the accuracy of the determination of retroreflectivity values.

In contrast to the existing techniques for determining retroreflectivity that require an operator to target individual signs from a known distance, a preferred embodiment of the present invention can determine retroreflectivity without targeting individual signs and can automatically determine sheeting classification as a result. To overcome the limitations imposed by the existing techniques, the preferred embodiment employs several enhancements that are designed to improve the accuracy of evaluating intensity measurements made over a view where the reflective surfaces are not individually targeted and therefore neither the distance to the reflective surface or the normal vector to the reflective surface are known.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a capture vehicle used in a preferred embodiment of the present invention.

FIG. **2** is a data flow diagram of a preferred embodiment of the present invention.

FIG. **3** depicts a block diagram of the systems, subsystems and processes for capturing and processing roadside information from a moving platform in order to compute retroreflectivity according to the teaching of the present invention, wherein the arrows connecting the blocks of the diagram illustrate the connections between the systems and subsystems for computing R_A for each reflective asset recorded by the system of the present invention.

FIG. **4** depicts in diagram form, a preferred configuration of a sensor suite for use with a four-wheeled vehicle and the interconnections and couplings between the physical subcomponents of a system designed according to the present invention.

FIG. **5** is a plan view of a divided multi-lane vehicle pathway and depicts how periodic light intensity measurements may be made as a vehicle traverses the vehicle pathway over time and the discrete locations where such periodic light intensity measurements are performed by a data acquisition vehicle operating in accordance with the present invention.

FIG. **6** depicts four digital frames of data as captured by the intensity sensor at various discrete locations along the vehicle pathway depicted in FIG. **5**.

FIG. **7** depicts a flowchart showing the steps required to convert intensity measurements into foreground and background retroreflectivity for a single reflective asset.

FIG. **8** depicts a typical light source intensity profile over the visible electromagnetic spectrum, which illustrates how different wavelengths of electromagnetic radiation possess different light intensities.

FIG. **9** depicts a preferred methodology for creating a retroreflectivity profile for all lanes and locations adjacent a vehicle pathway for a single reflective asset or sign which retroreflectivity profile is based upon a single pass of a data acquisition vehicle over the vehicle pathway.

FIG. **10** illustrates the facts that the normal vector of a reflective asset and the sheeting type of such a reflective asset create symmetry that may be used to determine retroreflec-

tivity values along all rays (or vectors) that have the same relative angle to the normal vector of the reflective asset.

FIG. **11** depicts the concept of observation angle (i.e., angle between incident light from a light source and an human observer (or light sensor), of the light as reflected from the face of a reflective asset) in the context of a conventional passenger vehicle traversing a vehicle pathway and where light from the vehicle reflects from a stop sign to the vehicle operator (shown in ghost).

FIG. **12** depicts the concept of entrance angle (i.e., angle between incident light from a light source mounted to a vehicle and a normal vector relative to the substantially flat face of a reflective surface disposed adjacent a vehicle pathway).

FIG. **13** is a graphic representation of the retroreflectivity performance for white sheeting for the three main types of sign sheeting.

FIGS. **14**A, **14**A-**1**, **14**A-**2** and **14**B, **14**B-**1**, **14**B-**2** depict a flowchart for a preferred embodiment of the threshold algorithm used to determine sign sheeting type.

FIG. **15** depicts the geometry of entrance angle and observation angle for retroreflective pavement markings disposed upon a vehicle pathway.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1**, an acquisition vehicle **10** is equipped with multiple video cameras **12** that generate a series of raw videostreams **14** representative of a road or street over which the acquisition vehicle **10** is traveling. A global positioning satellite (GPS) receiver **16** supplies location information that is combined with the raw videostream **14** by a processor **18** to generate a tagged videostream **20**.

In one embodiment as shown in FIG. **2**, the tagged videostream **20** is analyzed by a computer processor **22** to identify each road sign **30** and generate an asset management database **24** containing attribute and location information associated with each road sign **30**. In an alternate embodiment, the identification of road signs **30** and generation of asset management database **24** is accomplished by the same processor **18** that tags the raw videostream **14**. The details of this process are set out in U.S. Pat. No. 6,453,056, issued Sep. 17, 2002 to Laumeyer et al., which is hereby incorporated by reference.

Either concurrent with or subsequent to the identification of road signs **30** and generation of asset management database **24**, the computer processor **22** evaluates that portion **32** of each video frame or image that depicts a road sign **30** to determine a set of color values **40**, **42** for each of a plurality of colors on the road sign **32**. A retroreflectivity value is generated for each color portion **34**, **36** on each frame of the tagged videostream **20** containing the road sign **30** that represents a different color value **40**, **42**. Preferably, the values for retroreflectivity are determined by measuring the intensity of the signal for each color portion **34**, **36**. These values are then analyzed over the number of frames containing each color portion **34**, **36** to arrive at the maximum retroreflectivity value **44**, **46** that corresponds to the color value **40**, **42** for each color portion **34**, **36** of the road sign **30**. These maximum retroreflectivity values **44**, **46** will be the reference values used in the threshold algorithm from which sign sheeting classification will be determined.

There are three main types of sheeting recognized in the industry: 1) Type I, commonly called Engineer Grade; 2) Type III, commonly called High Intensity; and 3) Type VII, commonly called Prismatic (Prismatic is sometimes divided into two groups—Type VIIa called Diamond Grade VIP, and Type VIIb called Diamond Grade LDP). In order to remove the manual element of determining sheeting type and measuring retroreflectivity, the automated system of the present invention must accurately distinguish between these sheeting types. To accomplish this, the present invention utilizes the fact that all signs use the same sheeting type for foreground and background colors, that each road sign will have at least two colors and that the reflectivity for each color for each type of sheeting material has a relatively unique minimum initial retroreflectivity value. Most signs also have either White, Yellow or Orange colors as one of the colors on the sign. According to 3M, a manufacturer of reflective sheeting material, each color of the three sheeting types has a minimum initial retroreflectivity value. The following table lists the minimum values for common colors of each type:

Color	Type I Min · R_A	Type III Min · R_A	Type VIIa Min · R_A	Type VIIb Min · R_A
White	70	250	430	800
Yellow	50	170	350	660
Orange	25	100	200	360
Red	14.5	45	110	215
Green	9	45	45	80
Blue	4	20	20	43

This information is stored in a reflectivity/color database **50**. The computer processor **22** accesses the database **50** using the maximum reflectivity value **44**, **46** that corresponds to the color value **40**, **42** for each color portion **34**, **36** to determine the lowest possible sheeting type for each color. If the sheeting type is classified the same for all of the color portions **34**, **36** for a given road sign **30**, then the sheeting class **52** is established as that type and this information is preferably stored in the asset management database **24** along with other attributes of the given road sign **30**. If there is a discrepancy in the classification of sheeting material between different colors, a subsequent analysis by the processor **22** using, for example, a neural network program, to incorporate other determining factors, such as time of day, shadow, direction that could affect the retroreflectivity of the lighter colors (white, yellow and orange) more than the retroreflectivity of the darker colors (red, green, blue). In general, retroreflectivity values for lighter colors are weighted more heavily in resolving any discrepancies in classification of sheeting material.

The system described herein acquires many data points along the desired roadway without specifically targeting any objects of interest. For a roadside sign, the specific geometry of the sign (its orientation with respect to the roadway) is not necessarily known, nor is it required. The retroreflectivity points determined along the roadway are generated for the "as placed" road sign. Road signs will display their best retroreflectivity performance (have the highest retroreflectivity values) at or near the normal vector for the sign face. Since the geometry of the as-measured sign is not known, the system chooses the highest retroreflectivity value for that sign as the value that will be used in the threshold algorithm for sign sheeting classification.

There are several factors that can cause retroreflectivity readings for signs to actually be lower than the values for the underlying sheeting type. For example, a sign that has a layer of dirt on the face will produce lower retroreflectivity numbers than usual. If these lower numbers are used in the threshold comparison algorithm, an incorrect sheeting type may

result. These systematic errors can be removed by analyzing the retroreflectivity profile for the sign.

Sign sheeting types vary by the intensity of light that is reflected, but they also have reflective characteristics that give them unique signatures. FIG. **13** shows the profiles for Type I, Type III, and Type VII white sign sheeting types. Note the unique profiles for the three sheeting types. The preferred embodiment of the present invention, due to its ability to utilize multiple retroreflectivity points, can determine sheeting type by matching the as-measured profile with a uniformly reduced (where the entire curve is multiplied by a scaling factor that is less than one) characteristic curve that best correlates to the as-measured profile. This correlation step will establish the "best fit" performance curve based on the shape of the curve, without consideration for the magnitude of the curve. This "uniform reduction" of the sign sheeting performance curve allows the proper sheeting type to be determined, thus overcoming the problem with signs that have some type of surface anomaly. The performance curve correlation described above can be used in one of two ways—either as a validation of the proper determination of sheeting type from the threshold algorithm or as one of the qualification criteria prior to performing the threshold algorithm.

The sheeting types are all manufactured with multiple layers. In order for the present invention to accurately compute retroreflectivity for purposes of determining sheeting type of a given road sign, it is also necessary for the system to recognize gross sheeting failures like extreme color fade, delamination and vapor fade (darkening of the daylight appearance of the sheeting due to the corrosion of the metal sign backing). These gross failures will impact R_A measurements of the sheeting. Preferably, the sheeting determination system described herein tests for the absence of these gross failures prior to making any R_A measurements as part of the process of categorizing sheeting type.

Retroreflectivity, designated as "R_A" generally (and from time to time in this disclosure), varies according to two key parameters, observation angle and entrance angle. Observation angle **100** (See FIG. **11**) is the angular displacement between a light source **110** and a light sensor **120**, as measured from an object face surface **130**. In the case of a vehicle **140** driven by vehicle operator **145** moving along a highway **150**, observation angle **100** is defined by the distance of the vehicle **140** from a sign face surface **130**, the placement of the light source (headlights) **110** on the vehicle **140**, and the position of the light sensor (eyes of the vehicle operator) **120** of the vehicle **140**.

Entrance angle **160** (See FIG. **12**) is defined as the angular displacement of the incident light **170** relative to the normal vector **180** from the object face surface **130**. Entrance angles are impacted by the angular position **200** of a sign **190** relative to the highway **150**, the sign **190** lateral distance **210** from the highway **150**, and the distance **220** of the vehicle **140** from the sign **190**. The inventors hereof are believed to be the first persons to successfully decrease the complexity and increase the efficiency of determination of R_A in the field.

The method of automated determination of R_A (See FIGS. **3** and **4**) preferably utilizes a plurality of subsystems located on/in a capture vehicle **225**. These subsystems include a light intensity measurement system **230**, a vehicle positioning system **240**, a color image capture system **250** and a data recording system **260**. The light intensity measurement system **230** preferably includes a high output light source **270**, a light intensity sensor **280** and an intensity measurement system control **290**. A plurality of intensity measurements **300** are generated by the intensity measurement system **230** in response to the repeated strobing of the high output light source **270**. The vehicle positioning system **240** preferably includes a GPS receiver **310**, an inertial navigation system **320**, a distance measuring instrument **330** and a master clock **340**. A position measurement **350** is generated by the vehicle positioning system **240**. The color image capture system **250** preferably includes a stereoscopic camera pair **360**, iris controls **370** and image capture control **380**. The image capture system **250** generates a digital imagery stream **390**.

The data required for the automated determination of R_A is accumulated while traversing a highway **150** with the capture vehicle **225** (See FIGS. **5** and **6**). The capture vehicle **225** is shown on a 4-lane divided highway **400** with the capture vehicle **225** located in a proximate lane **410** to the stop sign **190**. Preferably, a series of reflected light intensity frames **420** are generated at a constant measurement interval **430** as the capture vehicle travels along the highway **150**.

Characterization of sign **190** R_A preferably utilizes the data recording system **260** to create a single tagged videostream **440** from the reflected light intensity frames **420**, position measurements **350** and digital imagery **390** for each capture event **430** (See FIGS. **3**, **5**, **6**, **7**, and **8**). A computer processor **450** identifies an object of interest **460** in a portion of the intensity frame **420** and determines the object of interest attributes **465** associated with that object of interest. Preferably, the objects of interest are identified from the digital imagery stream **390** generated by the color image capture system **250** in the manner as taught by U.S. Pat. No. 6,266,442. Alternatively, other techniques known in the art for isolating an object of interest in a videostream can be used. Preferably, the computer processor **450** correlates the portion of an image frame of the digital imagery stream **290** with a similar portion of the intensity frame **420** containing the object of interest **460**.

For each object of interest **460**, a background intensity measurement **470** and a foreground intensity measurement **480** is generated. Using an intensity algorithm **490**, a light intensity sensor characterization **275** and a look-up-table **475**, the computer processor **450** determines a background luminance value **500** and a foreground luminance value **510**. Based on the background luminance value **500**, the foreground luminance value **510**, a characterization of light source wavelength **540**, the background sheeting color **505** and the foreground sheeting color **506** the computer processor **450** characterizes a background R_A **520** and a foreground R_A **530** which are preferably reported separately for that object of interest.

The automated determination of multiple R_A values for a given object of interest **460** allows for the extrapolation of R_A values at an unmeasured viewing point **550** for an object of interest, such as a sign **190** (See FIGS. **9** and **10**). In this example, the unmeasured viewing point resides in a nontraversed lane **560**. The computer processor **450** defines an undetermined retroreflectivity ray **570** for unmeasured viewing point **550**. Using interpolated values, the computer processor **450** determines an R_A value for unmeasured viewing point **550** and any point located along undetermined retroreflectivity ray **570**.

Pursuant to the teaching of the present invention, a method and apparatus for determining retroreflectivity of relatively flat surface portions of objects disposed adjacent a highway **150** traversed by a vehicle **140** are taught, enabled, and depicted. The present invention may be utilized to detect and determine a retroreflective surface of interest disposed in a scene of non-retroreflective surfaces. That is, at least one object face surface **130** which exhibits retroreflectivity over at

least a relatively narrow conical volume of magnitude of several degrees from a normal vector **180** originating from said object face surface **130**.

In accordance with the present invention, a determination of the retroreflectivity of objects adjacent a highway **150** preferably includes providing: (i) position measurements **350** of a capture vehicle **225**; (ii) precise position of the object of interest **460**, or sign **190**; (iii) intensity measurements **300** from a high output light source **270** and light intensity sensor **280** at measurement intervals **430** along said highway **150**. Thus, a single-pass along the highway **150** by the capture vehicle **225** operating the light intensity measurement system **230**, vehicle positioning system **240**, image capture system **250** and data recording system **260** taught herein eliminates many shortcomings of the prior art and allows a single vehicle operator to conduct virtually continuous data measurement and acquisition of objects of interest **460** disposed adjacent a highway **150**, at capture events **430** on said highway **150**, without disrupting or interrupting other vehicle traffic traversing said highway **150**.

FIG. **3** shows a block diagram of the on-board systems and the desktop systems required to record a tagged videostream **440** and create sign R_A profiles **590** for various signs **190** along a highway **150**. The vehicle positioning system **240** contains all of the equipment to precisely locate the capture vehicle **225**. All location information is synchronized with a master clock **340** preferably associated with a computer processor **450**, which allows other data types to be merged with the vehicle location information at later stages in the post-processing. All of the on-board systems utilize the same master clock **340** information, thus allowing any events (image capture system **250**, intensity measurement **300**, and trigger controls **227**, **228**) to be correlated to the precise vehicle location and attitude during real-time, near real-time, or post-processing of the data acquired by the capture vehicle **225**.

The image capture system **250** consists of at least one set of stereoscopic cameras **360** that gather digital imagery along the highway **150**. Each capture event is combined with time stamp information from the vehicle positioning system **240** which also provides trigger control **227** for the image capture system **250** and trigger control **228** for the light intensity measurement system **230**. These images and associated time stamps are later combined with photogrammetry to create objects of interest **460** and their associated attributes **465**.

The light intensity measurement system **230** preferably consists of at least one high output light source(s) **270** and the associated light intensity sensor(s) **280**. The precise control for these items is contained within the light intensity measurement system **230**, and master time sequencing instrument **340** information received from the vehicle positioning system **240** (or computer processor **450**) is combined to create a tagged videostream **440** so precise vehicle information can be utilized during post-processing.

The data recording system **260** is constantly monitoring control information from the other three on-board systems and records the necessary information. No post-processing is performed in the data recording system **260**. As computer power increases in the future, one skilled in the art could produce a system whereby most, if not all, of the post-processing functions were performed in the capture vehicle **225**, perhaps even in real time. The inventors can imagine several uses for the production of real-time information from the image capture system **250** in the future, but the cost of obtaining such information with today's computing power makes this option prohibitively expensive today.

The lower half of FIG. **3** shows the functional blocks for data post-processing. There are two main functions—the creation of objects of interest **460** and their associated attributes **465**, and the determination of retroreflectivity for each object of interest **460**. There are many methods for creating objects of interest **460** from digital imagery, a few of which are discussed in this disclosure. The specific steps required to compute R_A are outlined in the discussion below.

FIG. **4** shows a typical configuration within a capture vehicle that is capable of producing data and imagery to create digital representations of objects of interest **460** and objects of interest retroreflectivity **466**. The distance measuring instrument (DMI) **330**, GPS receiver **310** and inertial navigation system (INS) **320** constitute the vehicle positioning system **240**. Not all of these components are necessary to obtain the desired results, but better precision, and therefore more meaningful data, are produced if all three components are included.

The high output light source(s) **270** and light intensity sensor(s) **280** constitute the light intensity measurement system **230**. These components make it possible to gather on-the-fly information for a desired highway **150** to allow the computation of object of interest retroreflectivity **466**, as well as create a full 3-D sign R_A profile **590** for those same objects of interest **460**.

The stereoscopic cameras **360** constitute the digital imagery system **390** that allows for the creation of objects of interest **460** and their associated attributes **465** during post-processing. More than one set of stereoscopic cameras **360** can be employed, thus increasing the accuracy of positional measurements for objects of interest **460**. Other, non-stereoscopic imaging systems could also be employed with little or no change to the vehicle positioning system **240** or to the light intensity measurement system **230**.

FIG. **5** shows the top view of a 4-lane divided highway **400** with a stop sign **190**. The capture vehicle **225** is traveling in the proximate lane **410** to the stop sign **190** and makes intensity measurements **300** at capture events **430** while traveling the depicted route. The techniques described herein will allow a retroreflectivity value for this stop sign **190** to be computed for any point along the 4-lane divided highway **400**, independent of whether the intensity measurement **300** was made at that point and also independent of whether the capture vehicle **225** actually drove over that point.

It should be noted that intensity measurements **300** are made continuously while the capture vehicle **225** is in motion, thus requiring no prior knowledge of either the positions or the existence of signs.

FIG. **6** shows some typical reflected light intensity frames **420** as captured by the light intensity sensor **280** at various discrete locations along the roadway. These reflected light intensity frames **420** are the result of the high output light source **270** being energized (or flashed) while each reflected light intensity frame **420** is captured by one or more light intensity sensors **280**. Since most of the objects in the scene are not reflective, and due to the high setting of the threshold range in the light intensity sensor(s) **280**, the reflected light intensity frames **420** will actually show very few objects. For effective luminance results throughout a wide range of retroreflective materials, more than one light intensity sensor **280** may be required in order to get enough levels of gray within the active part of the visible spectrum. When multiple light intensity sensors **280** are required or used, they may each have different threshold ranges and each thus detect luminance values in different parts of the desired luminance ranges.

In order to compute retroreflectivity (R_A), one needs to know the luminance of the reflected energy. Luminance (expressed in candelas per square meter, or cd/m^2) will vary

according to the intensity sensor characterization profile **275** of the light intensity sensor(s) **280** and the color of the material from which light is reflected.

Most roadway signs **190** contain text and/or symbols overlaid on a background. To ensure maximum visibility during day and night conditions, the colors of the foreground information (text and/or symbols) are chosen to have maximum day and night contrast with the background material. The techniques taught herein allow the retroreflectivity of roadway signs **190** to be determined for both foreground and background materials. Computing both the foreground **530** and background retroreflectivity **520** for each object of interest **460** allows us to ensure that the proper nighttime contrast is achieved for roadside assets. For example, a stop sign **190** with a red background and white lettering can provide good daytime contrast between the text and the sign background. But if these two materials display very similar retroreflectivity characteristics, their nighttime contrast will be minimal, thus rendering the sign ineffective during nighttime conditions.

FIG. **7** shows a block diagram of the steps required to transform intensity measurements **300** into foreground luminance values **510** and background luminance values **500**. First, a black and white camera is preferably used as a light intensity sensor **280** to maximize the sensitivity of intensity measurements **300** (intensity will be determined from the gray value of the corresponding pixels). Think of an intensity measurement **300** as intensity values for N discrete points within the scene, where N corresponds to the number of pixels in the light intensity sensor's **280** array. For a light intensity sensor **280** that has a resolution of 640×480 pixels, there are 307,200 discrete intensity values for each intensity sensor measurement **300**. Although the preferred embodiment utilizes an intensity sensor measurement **300** in the form of an array of discrete pixel intensity values, preferably a single pixel intensity value is selected and utilized for the automated determination of a corresponding retroreflectivity value. Alternatively, an average or other combination of a group of pixel intensity values could be utilized for the automated determination of a corresponding retroreflectivity value. Intensity values will vary according to the color of the reflected light, since not all colors of incoming light excite the light intensity sensor **280** pixels in the same way. By knowing the background or foreground color of the object of interest **460** along with the light intensity sensor's **280** ability to sense, or the light intensity sensor's **280** profile for a particular color, the intensity value **300** for a particular color can be converted into a luminance value. Light intensity sensor **280** characterization is essential for high precision computations since N photons of a given particular color (or wavelength) of light will represent a different gray value (intensity level) in the sensor than N photons of another color (or wavelength) of light. The look-up-table (LUT) **475** shown in FIG. **7** is a digital table stored in memory that uses the indexes of intensity (a single gray level value from the intensity measurement **300**) and sheeting color to determine the luminance. The light intensity sensor characterization **275** is empirical information about the light intensity sensor **280** that is used to create the LUT **475**. The same LUT **475** is used for computing foreground **510** and background luminance values **500**.

The reader should note and appreciate that luminance is strictly a measure of the reflected light, while retroreflectivity (or R_A, expressed in candelas/lux/m^2) is a measure of the reflected light with respect to the incident light for that object. FIG. **7** shows the information needed to accurately convert luminance to R_A: sensor location, object location, light source characterization, and color of reflective material. For less precise R_A computations, a subset of the aforementioned characteristics can be utilized. For example, if a uniform light source (equal intensity throughout the scene), columnated light reflected from the surface of the object of interest **460**, and a known distance **220** between the object of interest **460** and the light intensity sensor **280** are all assumed, then the sheeting color and luminance value may be used to determine a rough approximation (within 20%, for example) for R_A.

To obtain the highest quality R_A calculations, all of the data shown in FIG. **7** should be utilized. The characterization of light source angle defines the amount of light emitted from the high output light source **270** throughout the source's field of view. Due to the limitations of lamp design and their associated reflectors, most semi-uniform light sources will have their greatest intensity at or near the normal vector for the light source. Since the high output light source(s) **270** are not aimed at objects of interest **460**, the part of the incident light beam that is striking the object of interest **460** when the intensity measurement **300** is captured must be determined. Light source angle characterization is a process whereby empirical data from the light is modeled to establish the light intensity for numerous discrete vectors from the center of the light. When intensity values are determined for a discrete point in the scene (from the object's face surface **130**), the light intensity sensor **280** location and heading, as well as the object of interest **460** location, are used to determine which light vector emanating from the light source was responsible for the resulting intensity measurement. The characterization of light source angle therefore, is a look-up-table where an object of interest's **460** angular displacement from the normal vector **180** for the high output light source **270** is converted to a light intensity for the associated vector.

Since the beam from the high output light source **270** is diverging, objects of interest **460** farther from the origin of the light will receive less incident radiation than those objects of interest **460** closer to the light. The characterization of light source angle is constructed at a few discrete distances from the light. Simple geometry can be used to compute the incident radiation (using an interpolation method for an actual distance between two discrete distances in the characterization of light source angle) hitting the actual object of interest **460** based on the empirical data from the characterization of light source angle.

The preferred high output light source **270** is a uniform full-spectrum (visible spectrum) light. In practice, this light source will not emit the same intensity for all wavelengths of visible light. One variable of light source color characterization that should be considered is the output profile of the light throughout the visible spectrum. FIG. **8** shows a typical full-spectrum light source output profile. Note that the intensity in the blue area (400-500 nm) of the spectrum is stronger than in the red area (600-700 nm). This profile specifies the amount of light energy (number of photons) emitted for a given frequency. Since R_A depends on the intensity of the incident light, the light source color characterization **540**, light source angle characterization **535**, background sheeting color **505** and foreground sheeting color **506** must be combined to determine how the background luminance value **500** and foreground luminance value **510** is converted to R_A (i.e., what percent of the incident photons of the foreground/background color were reflected back to the sensor).

The divergence pattern for the light source may have different profiles for various portions of the visible spectrum. In practice, a separate light source angle characterization profile may be required for each possible foreground and background color of any given object of interest **460**.

A preferred high output light source **270** is of the type set forth in the attached installation and operation guide entitled "StrobeGuard™ High Intensity Obstruction Lighting System, Model No. SG-60," manufactured by Honeywell, Inc. In order to create a useful sign R_A profile **590** for an object of interest **460**, intensity measurements **300** for frequent capture events **430** along a highway **150** while the capture vehicle **225** is in motion. For example, at vehicle speeds of 50 miles per hour, intensity measurements **300** should be taken at a rate of at least two per second. The StrobeGuard™ SG-60 model has a recharge time of about 1.5 seconds between successive flash events. As a result, one SG-60 light will not provide enough flash events per second to allow an adequate number of intensity measurements **300**. In order to meet the requirements of two flash events per second for a capture vehicle **225** traveling at 50 miles per hour, three of the StrobeGuard™ SG-60 units would need to be fired in a synchronized, round-robin pattern to obtain enough trigger events.

The light intensity measurement system **230** described herein attempts to remove observation angle **100** as an R_A variable. This is done by keeping the offset between the high output light source(s) **270** and light intensity sensor(s) **280** as low as possible. As mentioned previously, an R_A profile of a simulated roadway **580** can be computed, even though the intensity was not measured at every point and even though the capture vehicle **225** did not drive over every point. First, it is critical that the geometry of R_A is understood. Reflective materials like sign sheeting are designed to project near-columnated light back toward the light source. If a perfectly columnated light being reflected from the object of interest **460** being measured and a zero observation angle are assumed, the R_A values for all discrete locations along a ray projected from the object will be identical.

FIG. **9** shows how to compute R_A for any discrete location along a 4-lane divided highway **400**. The R_A value for the desired point will be based on the R_A value that lies along the pathway traveled by the data acquisition vehicle **225**. To compute this "reference R_A value" (the R_A value for a discrete location on or along a vehicle path), an undetermined retroreflectivity ray **570** is drawn from the desired location to the face of the reflective asset. The discrete location where the undetermined retroreflectivity ray **570** intersects the vehicle path will be used as the reference R_A value. Since the discrete location on the vehicle path will always lie between two measured locations where intensity measurements **300** were made, the reference R_A value is computed by interpolating the two closest (in distance) R_A values along the vehicle path. As used herein, interpolate has the usual and typical meaning. It will be understood that interpolation consistent with the present invention can involve interpolation followed by extrapolation and shall also include such other special mathematical expressions used or created to account for border effects and effects at the lateral periphery and at the furthest distance where R_A may be reliably determined by application of the teaching of this disclosure.

If perfectly columnated light is assumed, the value of R_A at the desired point will be the same as the reference R_A value. In practice, all sign **190** sheeting materials will have some beam divergence for reflected light. This beam divergence information can be used to adjust the computed R_A value up (or down) from the reference R_A value for discrete locations closer to (or farther from) the object's face surface **130**.

While knowing the normal vector **180** to a sign **190** face is not required, there are some advantages for planning and maintenance purposes that make the information useful. Several ways to compute the normal vector **180** for a sign **190** exist. First of all, the "assumption" method requires that the normal vector **180** from the surface of the sign **190** is assumed to be parallel to the capture vehicle pathway **410** at the nearest location of the capture vehicle pathway **410** to the sign **190**. Second, a scanning laser operating in conjunction with an optical sensor and having a common field of view may be used to more precisely resolve the normal vector **180** from the object's face surface **130**. Third, stereoscopic cameras **360** may be employed in a useful, albeit very imprecise manner of determining the normal vector **180**. Fourth, the assumption method and stereo imaging method may be combined whereby the normal vector **180** is assumed to lie parallel to the vehicle pathway **410** unless the stereo imaging output renders the assumption false.

Of the methods listed above, the highest precision measuring systems for determining the normal vector **180** consists of a scanned laser and associated optical sensor. This combination yields relative distance measurements between the capture vehicle **225** and the object's face surface **130** that are more precise than optical measurements with cameras. A laser scanner attached to the capture vehicle **225** and directed toward a roadside scene populated with retroreflective signs **130** generates a series of reflection points to the optical sensor that appear as a horizontal segment of points. The optical sensor must be fast enough (i.e., have adequate data acquisition rates) to capture at least several individual discrete measurements across the object's face surface **130** (or of any other reflective asset). In general, two types of laser scanners are suitable to be utilized according to the present invention; namely, single-axis scanners and dual-axis scanners. A preferred sensor is of the type set forth in the proposal entitled, "Holometrics 3-D Vision Technology," as referenced in the previously identified provisional patent application.

Since most all types of roadside signs **190** to be measured are disposed at various elevations relative to the highway **150** and the capture vehicle **225**, a single-axis laser scanner cannot be mounted such that the scanning laser beam covers only a single elevation or constant height relative to the highway **150** and the capture vehicle **225**. Rather, the inventors hereof suggest that use of a single-axis type laser scanner must either be mounted high on the capture vehicle **225** with a downward facing trajectory, or be mounted low on the capture vehicle **225** with an upward facing scanning trajectory. These two mounting schemes for a single-axis laser scanner help ensure the lateral scan will intersect with virtually every object face surface **130** of all signs **190** or other objects of interest **460** present in a roadside scene regardless of the elevation or height or such signs relative to the roadway or to the moving platform.

Dual-axis laser scanners **335** circumvent the varying sign height problem inherently encountered if a single-axis laser scanner is employed as the source of integrated energy when practicing the teaching of the present invention. A dual-axis laser scanner **335** operates by continuously moving the scanning beam scan up and down at a relatively slow rate while sweeping the laser beam laterally from side to side across the field of view at a relatively more rapid rate.

In order to obtain the normal vector **180** for a sign **190** as taught hereunder, only a select horizontal series of discrete locations across the object's face surface **130** needs to be sensed by the high-speed optical sensor. For each point in the horizontal series of discrete locations recorded for a given sign **190** due to the incident radiation provided by the scanning laser, as sensed by the high speed optical sensor, the precise direction of the incident laser is recorded, thus allowing both distance and direction of the measured point to be determined.

Either of the scanning methods produces a massive number of sensed discrete locations representing discrete reflections of the incident laser radiation and each must be processed in order to correlate each of the sensed discrete locations with the object's face surface **130**. Once the lateral series of discrete locations for a sign **190** is determined, simple triangulation methods are used to combine: (i) the vehicle location, (ii) vehicle heading vector, and (iii) scanned sign point to ultimately determine the normal vector **180** for the object's face surface **130**.

As stated earlier, knowing the sign's **190** normal vector **180** can expand the utilization of the present invention. The retroreflective properties of sign **190** sheeting materials are typically symmetrical about the vertical axis of the object's face surface **130**. Because of this symmetry, R_A values (either computed or extrapolated/interpolated values) will be identical for rays that are symmetrical about the vertical axis.

FIG. **10** shows how the sign's **190** normal vector **180** can be used to extrapolate more R_A points. The R_A value for Point B is the same as the R_A value for Point A since their angle relative to the normal vector **180** is the same and since their distance from the sign **190** is the same. If Point B has the same relative angle (from the sign's **190** normal vector **180**) as Point A, but lies closer to (or farther from) the object's face surface **130**, the sign **190** material's beam divergence profile can be used to adjust the R_A value for Point B up (or down) from the value obtained for Point A.

The image capture system **250** and light intensity measurement system **230** are preferably free running, with measurements being made periodically during capture vehicle **225** operation. There is no requirement that these two systems be synchronized. In fact, these systems could operate in completely different capture vehicles **225**, if necessary. When both systems are contained within the same capture vehicle **225**, the only constraint for simultaneous operation is placed on the image capture system **250**. Because of the intensity of the high output light source **270** in the light intensity measurement system **230**, it is preferred that the image capture system **250** not capture frames at the same instant that the high output light source **270** is triggered. If images are actually captured while the high output light source **270** is triggered, their positional results would still be valid, but the colors displayed would be inaccurate because of the high output light being directed toward the (typically lower-thresholded) stereoscopic cameras **360**.

One skilled in the art could completely eliminate any need for the image capture system **250** to know the firing events of the light intensity measurement system **230** by choosing sampling rates for the two systems that do not share any harmonic frequencies. On the rare occasions when the image capture system **250** captures images while the high output light source **270** is energized (or flashed), the skilled implementer could use time stamps to determine when this system simultaneity occurred and discard the imaging frames.

Referring now to FIGS. **14**A, **14**A-**1**, **14**A-**2** and **14**B, **14**B-**1**, **14**B-**2**, a preferred embodiment of the flowchart for the sign sheeting threshold algorithm will be described. In the preferred embodiment, certain assumptions are made that simplify the threshold algorithm process. It will be understood that additional assumptions could be made to further simplify the process, or that the process could be further expanded to allow certain of the assumptions to be avoided. In the preferred embodiment, it is assumed that each road sign **30** has only two colors of reflective sheeting and that the sheeting type is the same for both the background sheeting color **505** and the foreground sheeting color **506**. It is also assumed that the retroreflectivity for both the background R_A **520** and the foreground R_A **530** are non-zero values. As previously described, the algorithm assumes that prefiltering has eliminated retroreflectivity values for road signs **30** that demonstrate some type of gross failure of the sheeting material, such as delamination, excessive surface wear, extreme color fade, vapor fade, graffiti, or excessive dirt or other obstructions that would prevent an accurate determination of the retroreflectivity value. Such filtering is preferably accomplished by image analysis of the color images using any number of known image analysis techniques for characterizing anomalies in images.

The sign sheeting threshold algorithm process is initiated at step **600**. At steps **610**-**624**, the background sheeting color **505** is compared to a series of known sign sheeting colors. If the background color is yellow-green as determined at step **610**, then the sign sheeting type is classified as Type VII as step **628**. If the background color is white as determined at step **612**, then the background R_A **520** is compared to the maximum retroreflectivity values for different sheeting types at steps **630**, **632**. If the background R_A **520** is less than the maximum white retroreflectivity value for sheeting Type I as determined at step **630**, then the sign sheeting type is classified as Type I at step **634**. Otherwise, if the background R_A **520** is less than the maximum white retroreflectivity value for sheeting Type III as determined at step **632**, then the sign sheeting type is classified as Type III at step **636**. If neither steps **630** or **632** are satisfied, then the sign sheeting type is classified as Type VII at step **638**. A similar process is repeated for colors yellow at step **614** and steps **640**, **642**, orange at step **616** and steps **644**, **646**, red at step **618** and steps **650**, **652**.

If the background color is either green, blue or brown, as determined at steps **620**, **622** and **624**, then a second determination is made at step **660** whether the foreground color **506** is white and at step **670** whether the foreground color is yellow. If step **660** is satisfied, then the foreground R_A **520** is compared to the maximum retroreflectivity values for different sheeting types at steps **662**, **664**. If the foreground R_A **530** is less than the maximum white retroreflectivity value for sheeting Type I as determined at step **662**, then the sign sheeting type is classified as Type I at step **666**. Otherwise, if the foreground R_A **530** is less than the maximum white retroreflectivity value for sheeting Type III as determined at step **664**, then the sign sheeting type is classified as Type III at step **668**. If neither steps **662** or **664** are satisfied, then the sign sheeting type is classified as Type VII at step **669**. A similar process is repeated for the yellow foreground color at steps **672** and **674**.

In the event that the background color **505** was not identified in steps **610**-**624** or the foreground color **506** was not identified in steps **660**, **670**, the sign sheeting type is considered undetermined at step **680**. It will be understood that various options can be undertaken at step **680**, including obtaining another color image and set of retroreflectivity values for the given road sign either with or without additional filtering or preprocessing of the raw data, marking the image and data for further review by an operator, discarding the information and marking the road sign as needing manual investigation, marking the road sign as needing replacement, or any combination of these or other operations.

Although the preferred embodiment of the threshold algorithm has been described with respect to the use of maximum retroreflectivity values, it will be understood that the threshold algorithm could utilize either minimum or maximum retroreflectivity values. Similarly, the combinations and orders of comparison of the colors and foreground or background colors may be altered and additional comparisons

may be made to accommodate additional sheeting types that may be developed. Preferably, the colors **505** and **506** are determined based on CIELUV color values as evaluated by the image capture system **250**. Alternatively, other equivalent color value systems such as RGB could be used for the color values. Preferably, the color values for the comparisons are a range of values specified by the manufacturer of the sheeting material. Alternatively, the color values for the comparison can be ranges of values empirically established.

As mentioned earlier observation angle is a key determinant for sign R_A behavior. The intensity system contained herein attempts to eliminate this variable by placing the light source(s) and sensor very close to one another. Planning departments can change observation angles within the R_A profile software to understand its impact on sign performance. Since the R_A profile software knows the as-measured sign sheeting type and have available an R_A performance profile preferably embedded in a look up table of all popular or required sheeting types and/or as stored in memory, or dynamically generated for use in practicing the present invention. A new R_A profile can then be generated for the newly-desired observation angle. FIG. **15** shows the R_A profile for our sign along our sample roadway when the observation angle is changed from its present value to a higher value.

Reflective pavement markings display similar properties to reflective assets (and other reflective objects), but the measurement of pavement marking retroreflectivity requires some extra constraints. Pavement marking retroreflectivity is measured in millicandelas per square meter per lux (mcd/m^2/lux) and is designated R_L. Along with observation angle and entrance angle, the lateral distance between the light source and the measured point must also be known. FIG. **15** shows the R_L geometry for a typical passenger vehicle.

Studies have shown that there is no correlation between pavement marking retroreflectivity (R_L) values with different geometries. Because of this lack of correlation, agreed-upon geometries must be utilized when measuring and reporting R_L.

When measuring and computing R_A we attempted to dramatically reduce (essentially eliminate) observation angle with the light source and intensity sensor placement. When measuring intensity for computing R_L, we need to position the light source and intensity sensor such that our agreed-upon geometry is met for the desired measurement distance. At the time of this disclosure, both the European Committee for Normalization and the American Society for Testing and Materials (ASTM) have standardized on the same R_L geometry of 1.05 degree observation angle, 88.76 degree entrance angle, and 30 meter measurement distance.

The intensity of light reflected from pavement markings will be less than that of signs. As a result, we'll need another intensity sensor for the determination of R_L. Therefore, we have two reasons for requiring a different intensity sensor for measuring R_A and R_L—the range of intensities and the placement of the sensor. However, the same high intensity light source (s) can be used for determining R_A and R_L.

Using the enabling teaching, written description, documents incorporated, and the illustrations and examples herein, one may:

- Create three dimensional (3D) color-coded representations of data collected from reflective surfaces on objects of interest showing retroreflective surfaces on objects of interest showing retroreflectivity for any or all such objects in an area and using real or experimental lighting sources and conditions.
- Improve upon existing (and create new) product life and aging models by comparing actual data collected from the field and comparing predictive models for same.
- Improve scheduling procedures for personnel who repair, replace, and install reflective assets by identifying damaged or poorly performing retroreflective assets or surfaces of signed and optionally subject to a preselected priority sequence.
- Create a sensor suite assembly, sensor platform and methods to systemically collect retroreflectivity data for all reflective assets in an area for comparison to applicable regulations, guidelines, and laws.
- Accident recreation(s) and/or traffic stimulation(s).
- To monitor vehicle manufacturer compliance with applicable vehicle lighting regulations, guidelines, and laws.
- To measure, monitor, and compare retroreflectivity, sheeting type, luminance and/or brightness between and among certain reflective objects depicted in a scene to ensure that the regulatory, warning, and information signage present in the scene are reasonably visible to motorists traversing the scene.

The teaching hereof is applicable to capture data from reflective surfaces of all varieties present in a scene, including without limitation, whether the surface is present in: (i) a scene from and including sea or water vehicle routes: (ii) a scene from and including air and space vehicle routes: or, (iii) a scene from and including terrestrial pedestrian and vehicle routes and the like. The invention hereof is also applicable to measuring R_L of reflective markings placed on the surface of vehicle pathways.

Additional advantages and modifications will readily occur to those skilled in the art. The invention in its broader aspects is, therefore, not limited to the specific details, representative apparatus, and illustrative examples shown and described. Accordingly, departures from such details may be made without departing from the spirit or scope of the applicant's general inventive concept.

The invention claimed is:

1. An automated method for classifying a reflective road marker having at least one color comprising:

- using a light source to illuminate at least a portion of the reflective road marker as the light source is traversed along a roadway;
- collecting a plurality of light intensity measurements reflected from the at least a portion of the reflective road marker, the light intensity measurements corresponding to exemplary angular displacements of incident light from a reference position;
- providing a database of retroreflectivity profiles, each retroreflectivity profile having an associated known road marker type having a known color;
- and
- using a computer processing system configured to:
  - generate an as-measured retroreflectivity profile based on the plurality of light intensity measurements;
  - select at least one retroreflectivity profile from the database of retroreflectivity profiles that correlates to at least a portion of the as-measured retroreflectivity profile;
  - determine a road marker type from a set of road markers that is associated with the selected at least one retroreflectivity profile; and
- classify the road marker according to the color associated with the determined road marker type.

2. The automated method of claim **1**, wherein the as-measured retroreflectivity profile is a curve of retroreflectivity values calculated from the plurality of light intensity mea-

surements plotted as a function of the exemplary angular displacements of incident light from the reference position.

3. The automated method of claim **2**, wherein each of the exemplary angular displacements of incident light comprises an observation angle corresponding to one of a plurality of distances of the light source from the road marker.

4. The automated method of claim **3**, further comprising dynamically generating a new retroreflectivity profile based on a change in the observation angle.

5. The automated method of claim **2**, wherein each of the exemplary angular displacements comprises an entrance angle corresponding to one of a plurality of distances of the road sign from the road marker.

6. The automated method of claim **1**, further comprising determining a lateral distance between the light source and the illuminated portion of the reflective road marker.

7. The automated method of claim **1**, wherein the retroreflectivity profile is a characteristic curve including a plurality of known retroreflectivity values.

8. The automated method of claim **1**, wherein each of the plurality of light intensity measurements comprises an array of discrete pixel intensity values.

9. The automated method of claim **1**, wherein the step of using the computer processing to determine the road marker type:

calculates a degree of correlation between the as-measured retroreflectivity profile and the selected at least one retroreflectivity profile;

selects a type associated with the selected at least one retroreflectivity profile if the degree of correlation lies between an acceptable range of predefined values; and

identifies the road marker as exhibiting a failure if the degree of correlation lies outside the acceptable range of predefined values.

10. The automated method of claim **1**, further comprising providing a database of road markers that includes pavement markings, each pavement marking categorized according to a set of colors for the pavement markings that includes yellow, green, red and white.

11. The automated method of claim **10**, wherein each color of the set of colors for the pavement markings is associated with a known retroreflectivity value.

12. An automated method of assessing reflective surfaces disposed along a roadway comprising:

activating a light source as the light source is traversed along a roadway to illuminate an area that includes at least one reflective surface on a road marker, the road marker having a reflective characteristic;

determining a plurality of light intensity values with at least one intensity sensor directed to cover a field of view which includes at least a portion of the area illuminated by the light source; and

using a computer processing system configured to:

identify a portion of at least one light intensity value of the plurality of light intensity values associated with one of the at least one reflective surface of the road marker; and

analyze the portion of the at least one light intensity value of the plurality of light intensity values to determine an assessment for the reflective characteristic of the road marker.

13. The automated method of claim **12**, wherein activating a light source comprises synchronizing activation of a plurality of light sources to optimize light intensity reflected from the road marker.

14. The automated method of claim **12**, wherein activating a light source comprises activating a single light source.

15. The automated method of claim **12**, further comprising determining a luminance value utilizing the plurality of light intensity values and a characterization profile of the at least one light intensity sensor.

16. The automated method of claim **1**, further comprising determining a lateral distance between the light source and the illuminated portion of the reflective road marker.

17. An automated system for assessing reflective surfaces disposed along a roadway comprising:

a light source that is traversed along a roadway to illuminate an area that includes at least one reflective surface on a road marker, the road marker having a reflective characteristic;

means for determining a plurality of light intensity values directed to cover a field of view which includes at least a portion of the area illuminated by the light source; and

a computer processing system configured to:

identify a portion of at least one light intensity value of the plurality of light intensity values associated with one of the at least one reflective surface of the road marker; and

analyze the portion of the at least one light intensity value of the plurality of light intensity values to determine an assessment for the reflective characteristic of the road marker.

18. The automated system of claim **17**, wherein the computer processing system further comprises a color identification subsystem, the color identification subsystem configured to associate at least one color with the reflective characteristic of the road marker.

19. The automated system of claim **18**, wherein the at least one color is selected from a set of colors consisting of yellow, green, red and white.

20. The automated system of claim **17**, wherein the light source comprises a laser scanning device.

21. The automated system of claim **17**, wherein the light source comprises a vehicle headlight lamp.

22. The automated system of claim **21**, wherein the vehicle headlight lamp is selected from a group consisting of a light emitting diode, a xenon lamp, a halogen lamp, a fluorescent lamp, and an incandescent lamp.

23. The automated system of claim **17**, wherein the means for determining a plurality of light intensity values comprises a light sensor.

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