

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
21 July 2011 (21.07.2011)

PCT

(10) International Publication Number
WO 2011/085489 A1

(51) International Patent Classification:
B60R 11/04 (2006.01) *H04N 7/18* (2006.01)

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(21) International Application Number:
PCT/CA2011/000048

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(22) International Filing Date:
13 January 2011 (13.01.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/294,619 13 January 2010 (13.01.2010) US

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(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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(54) Title: VEHICULAR CAMERA AND METHOD FOR PERIODIC CALIBRATION OF VEHICULAR CAMERA

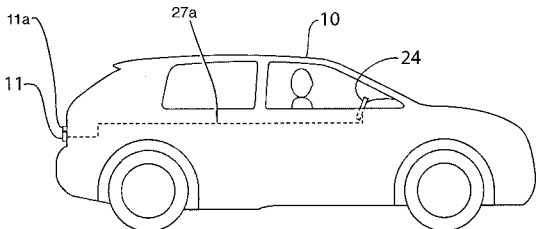


FIG. 1

(57) Abstract: In a first aspect, the invention is directed to a vehicular camera and a method for calibrating the camera after it has been installed in a vehicle. In particular, the invention is directed to calibrating a vehicular camera after the camera has been installed in a vehicle, wherein the camera is of a type that applies an overlay to an image and outputs the image with the overlay to an in-vehicle display.

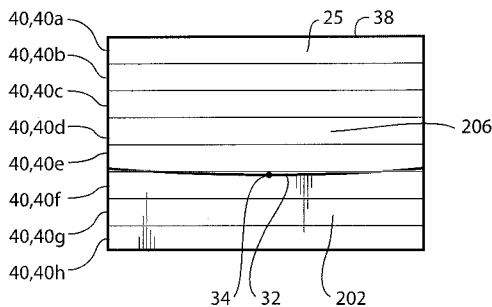


FIG. 7a

WO 2011/085489 A1

Published:

— with international search report (Art. 21(3))

**VEHICULAR CAMERA AND METHOD FOR PERIODIC CALIBRATION
OF VEHICULAR CAMERA**

5 **FIELD OF THE INVENTION**

[0001] The present invention relates to cameras for use in vehicles, and more particularly to a camera for use in a vehicle wherein an overlay is applied to the image on board the camera.

10 **BACKGROUND OF THE INVENTION**

[0002] A typical camera for mounting on a vehicle has a lens member, an imager, a circuit board and housing members that connect together. Some cameras have the capability to apply an overlay onto the image received by the imager, and to send the image with the overlay in it directly to an in-vehicle display for viewing by
15 the vehicle driver. Over time, however, it is possible that during use of the vehicle, the camera system can become misaligned. This can occur gradually from a variety of factors. It can also occur suddenly, such as, during an accident. Whether gradually or because of an accident, the misalignment can occur without being detected upon visual inspection of the camera.

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SUMMARY OF THE INVENTION

[0003] In a first aspect, the invention is directed to a vehicular camera and a method for calibrating the camera after it has been installed in a vehicle. In particular, the invention is directed to calibrating a vehicular camera after the camera has been
25 installed in a vehicle, wherein the camera is of a type that applies an overlay to an image and outputs the image with the overlay to an in-vehicle display.

[0004] In a particular embodiment, the camera includes a lens, an imager and a camera microcontroller. The camera is positioned to receive images from behind a vehicle including a portion of the bumper of the vehicle. The imager includes an
30 image sensor and an imager microcontroller. The image sensor is positioned to

receive light corresponding to images from the lens. The camera microcontroller is configured to apply an overlay to the images. The camera microcontroller is configured to receive data from the imager microcontroller relating to bars of pixels on the image sensor, wherein the microcontroller is further configured to detect a
5 reference point in the images using the data and is configured to determine an offset amount with which to shift the overlay on the images.

[0005] In a second aspect, the invention is directed to a method of calibrating a vehicular camera installed in a vehicle wherein the camera has an imager and a camera microcontroller, comprising:

- 10 a) determining whether the contrast in images received by the imager is beyond a selected threshold value;
- b) searching for a reference point in the images depending on the result of step a) using the camera microcontroller; and
- c) adjusting the position of an overlay applied by the microcontroller to
15 the images depending on the result of step b).

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The present invention will now be described by way of example only with reference to the attached drawings, in which:

20 **[0007]** Figure 1 is a side view of a vehicle with a camera in accordance with an embodiment of the present invention;

[0008] Figure 2 is a magnified view of the camera shown in Figure 1;

[0009] Figure 3 is an exemplary image received by the camera shown in Figure 1, with a static overlay on the image;

25 **[0010]** Figure 4 is an exemplary image received by the camera shown in Figure 1, with a dynamic overlay on the image;

[0011] Figure 5 is a schematic illustration of several components of the camera, communicating with a display in the vehicle shown in Figure 1;

- [0012]** Figures 6a and 6b are exemplary views from the camera of the bumper of the vehicle shown in Figure 1;
- [0013]** Figure 7a is a view of a search window in an exemplary image received by the camera of Figure 1, showing the division of the search window into a plurality of vertically stacked bars, used for determining the vertical position of a reference point in the image;
- [0014]** Figure 7b is a chart showing the gradients associated with the brightness levels of the vertically stacked bars shown in Figure 7a;
- [0015]** Figure 8 is a view of a search window in an exemplary image showing the division of the search window into a plurality of horizontally stacked bars;
- [0016]** Figure 9a is a view of a second search window in the exemplary image shown in Figure 7a, divided into a plurality of vertically stacked bars;
- [0017]** Figure 9b is a chart showing the gradients associated with the brightness levels of the vertically stacked bars shown in Figure 9a;
- [0018]** Figure 10a is a view of a third search window in the exemplary image shown in Figure 7a, divided into a plurality of vertically stacked bars;
- [0019]** Figure 10b is a chart showing the gradients associated with the brightness levels of the vertically stacked bars shown in Figure 10a;
- [0020]** Figure 11a is a view of a fourth search window in the exemplary image shown in Figure 7a, divided into a plurality of vertically stacked bars;
- [0021]** Figure 11b is a chart showing the gradients associated with the brightness levels of the vertically stacked bars shown in Figure 11a;
- [0022]** Figure 12a is a view of a fifth search window in the exemplary image shown in Figure 7a, divided into a plurality of vertically stacked bars;
- [0023]** Figure 12b is a chart showing the gradients associated with the brightness levels of the vertically stacked bars shown in Figure 12a;

- [0024]** Figure 13a is a view of a region of interest in which a plurality of search windows are selected, for determining the horizontal position of the reference point;
- [0025]** Figure 13b is a chart showing the pixel positions of the pixels having the highest associated gradients associated with the brightness levels search windows shown in Figure 13a;
- [0026]** Figure 14a a view of a plurality of selected search windows in the region of interest shown in Figure 13a to refine the determination of the horizontal position of the reference point;
- 10 **[0027]** Figure 14b is a view of another plurality of selected search windows in the region of interest shown in Figure 13a to refine the determination of the horizontal position of the reference point;
- [0028]** Figure 15 is a view of an image received by the camera of Figure 1, with a plurality of search windows selected therein, used to determine whether the contrast present in the image is sufficient to determine the position of the reference point;
- 15 **[0029]** Figure 16 is a view of the image shown Figure 15, with an initial search window selected therein, used for the selection of an exposure value to use for the image; and
- 20 **[0030]** Figure 17 is a view of a search window in an exemplary image illustrating a rotational offset for the camera.

DETAILED DESCRIPTION OF THE INVENTION

- [0031]** Reference is made to Figure 1, which shows a vehicle 10 that includes a camera 11 sends images 25 to an in-vehicle display 24. The camera 11 is configured to be calibrated periodically after it has been installed on the vehicle 10 in accordance with an embodiment of the present invention.
- 25

[0032] Reference is made to Figure 2, which shows the camera 11 in greater detail. The camera 11 includes a lens assembly 12, a housing 14, which may include a lens holder 14a and a rear housing member 14b, an imager 16 and a camera microcontroller 18.

5 **[0033]** The lens assembly 12 is an assembly that includes a lens 20 and a lens barrel 22. The lens 20 may be held in the lens barrel 22 in any suitable way. The lens barrel 22 may be held in the lens holder 14a in any suitable way.

[0034] The imager 16 may be any suitable type of imager 16 such as the imager model no. MT9V126 provided by Aptina Imaging, San Jose, CA and includes
10 an image sensor 16a, such as a CMOS sensor or a CCD sensor, and an imager microcontroller 16b that performs several functions. For example, the imager microcontroller 16b applies a distortion correction algorithm to the images 25 received by the image sensor 16a. Additionally, the imager microcontroller 16b applies graphical overlays to the images 25. Once the images 25 have been processed
15 by the imager microcontroller 16b they are sent to the in-vehicle display 24 via an electrical conduit shown at 27a, which may be, for example a coaxial cable.

[0035] The microcontroller 18 may be any suitable type of microcontroller, such as the microcontroller model no. PIC24HJ128GP502 provided by Microchip Technology, Chandler, AZ. The microcontroller 18 includes flash memory shown at
20 23 in which is stored the program for carrying out the periodic calibration of the camera 11.

[0036] External flash memory shown at 29 is used to store a plurality of overlays that can be applied to the images 25. Example overlays are shown in Figures 3 and 4 at 26. The overlay 26 shown in Figure 3 provides information regarding the
25 width of the vehicle 10 and rough distance information behind the vehicle. The overlay 26 shows the projected path of the vehicle 10 based on the current steering wheel angle of the vehicle 10.

[0037] The microcontroller 18 communicates with the imager microcontroller 16b via a bus, such as an I2C bus, shown at 27b, to provide information, such as the

location in the flash memory 29 from which the imager microcontroller 16b is to pull an overlay 26 to apply to the images 25.

[0038] While the camera microcontroller 18 and the imager microcontroller 16b communicate, the camera microcontroller 18 does not have access to the actual
5 pixel data from the imager 16.

[0039] Referring generally to Figures 1-4, during use of the vehicle 10, the camera 11 can become misaligned with respect to the vehicle 10, and the lens 20 and the imager 16 can become misaligned with each other. This can occur gradually from a variety of factors. It can also occur suddenly, such as, during an accident. Whether
10 gradually or suddenly (eg. because of a vehicular collision), the misalignment can occur without being detected upon visual inspection of the camera 11. The result is that the image 25 can shift in position on the imager 16. As a result, the overlays 26 or 28 applied by the microcontroller 18 to the image 25 can become misaligned with the image 25, since the image 25 is not in the position it was expected to be in when
15 the camera 11 was initially manufactured. If the vehicle driver relies on the overlays to guide him/her during a maneuver (eg. a backup maneuver into a parking spot), the misalignment could cause the driver to hit an obstacle that he/she believed was not in the path of the vehicle 10.

[0040] Periodically calibrating the camera 11 after it is installed in the vehicle
20 10 provides several advantages. One advantage is that the overlays 26, 28 applied to the image 25 by the microcontroller 18 will be properly aligned with the image 25 so that the driver of the vehicle 10 is provided with accurate position-related information from the overlays.

[0041] Referring to Figure 5, the camera microcontroller 18 does not have
25 access to the images 25 themselves that are received processed by the imager 16. Instead, the imager microcontroller 16b has a statistics engine 36 which is capable of providing certain types of statistical information regarding the image 25 to the camera microcontroller 18. Referring to Figures 7a and 8 the statistics engine 36 (Figure 5) can divide a selected search window 38 (ie. a selected section of the image 25), into a

plurality of vertically stacked bars 40 (Figure 7a), individually referred to at 40a-40h, or into a plurality of horizontally stacked bars 42 (Figure 8) individually referred to at 42a-42h, and can output the sum of the greyscale values within each bar 40 or 42 to the camera microcontroller 18 (Figure 5). In the embodiment shown, (ie. wherein the imager 16 is the MT9V126) the statistics engine 36 is configured to always break the search window 38 (Figures 7a and 8) into 8 bars 40 (Figure 7a) or 42 (Figure 8). It will be understood however, that in other embodiments, the statistics engine 36 (Figure 5) may instead be configured to break the search window 38 into more or fewer bars 40 or 42. Preferably, in an embodiment wherein the search window 38 is divided into 8 vertically stacked bars 40 (Figure 7a), the number of pixels (on the image sensor 16a) representing the height of the search window 38 is divisible by 8 so that each bar 40 is the same height (in terms of the number of pixels) and therefore contains the same number of pixels. Similarly, in an embodiment wherein the search window 38 is divided into 8 horizontally stacked bars 42 (Figure 8), the number of pixels (on the image sensor 16a) representing the width of the search window 38 is divisible by 8 so that each bar 42 is the same width and therefore contains the same number of pixels.

[0042] The camera microcontroller 18 is capable of calibrating the camera 11 periodically using the statistical data provided by the imager microcontroller 16b. To calibrate the camera 11, the microcontroller 18 determines whether there is any horizontal or vertical offset in the images 25 by searching for a reference point in the images 25 and comparing its actual position to its expected position. Optionally, the microcontroller 18 may also determine whether there is any rotational offset in the images 25 by searching for a plurality of reference points in the images 25 and comparing their actual positions with their expected positions. The results of the comparisons can then be used to apply linear and optionally rotational adjustments to the positions of the overlays 26 in the images 25.

[0043] The camera microcontroller 18 initially populates a database 110 with 50 (or some other selected number of) successful reference point detection cycles

before an adjustment is made to the positions of the overlays 26, and any adjustments to the positions of the overlays 26 is made based on the offsets determined in the 50 successful cycles. As an example, adjustments to the positions of the overlays 26 may be made based on the median values of the 50 past successful cycles. A successful
5 reference point detection cycle is a reference point detection cycle that is considered acceptable for addition to the database 110. Thereafter, with each new successful reference point detection cycle, the microcontroller 18 replaces the oldest record in the database 110 with the data from the new detection cycle. After each new successful detection cycle, the microcontroller 18 may adjust the positions of the
10 overlays 26, not based solely on the offsets found in the current detection cycle, but based on the running history contained in the database 110.

[0044] Referring to Figure 5, in an exemplary embodiment, the camera microcontroller 18 contains several program modules including a calibration manager module 100, a pre-processing module 102, a linear offset detection module 104, a
15 post-processing module 106 and an optional rotational offset detection module 108.

[0045] The calibration manager module 100 determines whether the conditions are appropriate to conduct any reference point detection cycle and sends control to the pre-processing module 102 if the conditions are appropriate.

[0046] Preferably, the microcontroller 18 conducts reference point detection
20 cycles on different driving days and at different driving times, with no more than one successful reference point detection cycle per day. Preferably, reference point detection cycles are taken at selected time intervals regardless of the amount of mileage that has been accumulated by the vehicle 10.

[0047] In an embodiment, the calibration manager module 100 triggers a
25 reference point detection cycle under the following conditions:

the vehicle is driving forward;

the in-vehicle display is not displaying camera images;

the vehicle is driving at least 40 km/hr

the vehicle's steering angle is no more than a selected amount of degrees away from zero;

the outside temperature is within a selected range;

the vehicle headlights are off;

5 the vehicle's heading direction is in a selected range of directions;

the vehicles wipers have been off for a selected period of time;

the time of day is within a selected range;

the amount of time the vehicle has been driving on the current trip exceeds a selected amount of time;

10 a valid calibration has not taken place already on the current day; and

a selected period of time has elapsed since the previous calibration.

[0048] If the above conditions are not met, the microcontroller 18 waits an additional selected period of time and then tries again to determine whether the conditions are met to trigger reference point detection cycle. If the vehicle 10 (Figure 1) is not running after the additional selected period of time, the microcontroller 18 waits until the vehicle 10 is next turned on and checks if the conditions are met at that time. If the conditions are met, the microcontroller 18 calls the pre-processing module 102.

[0049] The pre-processing module 102 assists in the selection of an exposure value to be used on images 25 received by the imager 16, and also determines whether the image 25 will have sufficient contrast to permit the structure on which the one or more reference points is present to be distinguished clearly from the background. In the embodiment shown in the figures the aforementioned structure is the vehicle bumper 202, and the background is shown at 206. If the pre-processing module 102 determines that the contrast is not sufficient in the image 25, then the reference point detection cycle is not run.

[0050] In the embodiment shown in the figures, the selection of the exposure to use on the images 25 is carried out by the imager microcontroller 16b based on a search window 203 (Figure 16) that is selected by the camera microcontroller 18 (Figure 5). The camera microcontroller 18 selects a search window 203 that includes
5 both a portion of the vehicle bumper 202 and a portion of the background 206.

[0051] Once an exposure is selected and images 25 are received by the imager 16, the pre-processing module 102 determines if the contrast in the images 25 is likely to result in successful reference point detection cycles. As noted above, the imager 16 does not provide the image 25 itself to the microcontroller 18, but instead provides
10 statistical information regarding a search window from the image 25. In order to determine whether the contrast is good, the pre-processing module 102 processes statistical data from a plurality of search windows shown in Figure 15, including a plurality of first search windows 200 (shown individually at 200a, 200b and 200c) which are on the bumper 202, and a plurality of second search windows 204 (shown
15 individually at 204a, 204b and 204c) which are on the background 206. Three search windows 200 and three search windows 204 are used in the embodiment shown, however it will be understood that a different number of search windows 200 and 204 may be used.

[0052] The positions and sizes of the search windows 200 and 204 are
20 selected so that even if the camera 11 (Figure 2) is misaligned by some amount, there is a strong likelihood that the search windows 200 will be on the bumper 202 and that the search windows 204 will be on the background 206.

[0053] The statistics engine 36 (Figure 5) divides each first search window 200 (Figure 15) into 8 horizontally stacked bars 208 and outputs the sum of the greyscale values of the pixels contained in each bar 208 to the microcontroller 18
25 (Figure 5). The microcontroller 18 takes the 8 sums and calculates the mean and variance of this data.

[0054] The statistics engine 36 divides each second search window 204 into 8 horizontally stacked bars 210 and outputs the sum of the greyscale values of the pixels

contained in each bar 210 to the microcontroller 18. The microcontroller 18 calculates the mean and variance of the 8 sums. The microcontroller 18 then determines whether the differences in the mean values between any two of the three windows 200 are less than selected threshold values. The microcontroller 18 also
5 determines whether the differences in the mean values between any two of the three windows 204 are less than selected threshold values. The microcontroller 18 also determines whether the difference in the mean values of each vertically adjacent pair of a window 200 and a window 204 is greater than a selected threshold value. In other words, the microcontroller 18 checks if the difference between the mean values
10 of the windows 200a and 204a is greater than a selected value, and checks if the difference between the mean value of the windows 200b and 204b is greater than a selected value, and so on. Additionally, the microcontroller 18 also determines if the variance of each window 200 and 204 is less than a selected threshold value. If all of the above conditions are met, then the pre-processing module 102 permits an
15 reference point detection cycle to be carried out. If any of these conditions are not met, then an reference point detection cycle is not carried out at that time.

[0055] In some embodiments, it is possible that the pre-processing module 102 could be programmed to determine a suitable exposure to use for the images 25 received by the imager 16. In one example, the pre-processing module 102 could
20 iteratively select exposures to use, refining each selection based on the results of the comparisons using the mean values and variances described above.

[0056] The linear offset detection module 104 determines the position of a first reference point in the image 25. The reference point to search for depends on the position of the camera 11. For example, in embodiments wherein the camera 11 is a
25 tailgate-mounted rearview camera (as shown in Figure 1), the first reference point may be a point on the vehicle bumper 202. In Figures 6a and 6b, the edge of the bumper 202 is shown at 32. As can be seen, the bumper edge 32 appears curved due to distortion in the image 25. Regardless of whether the bumper edge 32 is domed, as shown in Figure 6a, or is dished as shown in Figure 6b, the curved bumper edge 32

has an extremum, which is shown at 34. The extremum 34 may also be referred to as the first reference point 34.

[0057] Using the statistical information that the statistics engine 36 (Figure 5), the microcontroller 18 can determine the position of the extremum 34 (Figures 6a, 5 6b).

[0058] The microcontroller 18 (Figure 5) may first search for the vertical position of the first reference point 34, and may then search for the horizontal position of the first reference point 34.

[0059] Initially, a search window 38 (Figure 7a) is selected by the 10 microcontroller 18. The properties (ie. the size and position) of the search window 38 may initially be selected by the microcontroller 18 (Figure 5) based on the estimated position of the first reference point 34. The search window 38 selected in the exemplary embodiment shown in Figure 7a is 240 pixels wide by 160 pixels high.

[0060] The sums of the greyscale values of the vertically stacked bars 40 15 shown in Figure 7a are generated by the statistics engine 36 and sent to the microcontroller 18. The sums are represented mathematically as VAL(n), where n is the numerical position of the image bar 40 in the search window 38 (and is thus a value between 1 and 8 inclusive).

[0061] The microcontroller 18 calculates the absolute values of gradients 20 associated with the image bars 40 (referred to as absolute gradients). The absolute gradient at a particular image bar 40 is referred to as GRAD(n), where n is the numerical position of a particular image bar 40 in the search window 38. The absolute gradient is calculated as follows:

$$\begin{aligned} \text{GRAD}(n) &= \text{ABS}[(\text{VAL}(n+1) - \text{VAL}(n)) + (\text{VAL}(n) - \text{VAL}(n-1))] / 2 \\ &= \text{ABS}[\text{VAL}(n+1) - \text{VAL}(n-1)] / 2 \end{aligned}$$

25

[0062] Put in word form, the absolute gradient GRAD(n) of the nth image bar is the absolute value of the sum of brightness values in the next image bar minus the sum of brightness values in the preceding image bar, all divided by 2. It will be

understood that the formula above can be used for the second image bar 40b through to the seventh image bar 40g (ie. the second-to-last image bar). For the first image bar 40a:

$$\text{GRAD}(1) = \text{ABS}[\text{VAL}(2) - \text{VAL}(1)]$$

5 **[0063]** For the eighth (ie. last) image bar 40h:

$$\text{GRAD}(8) = \text{ABS}[\text{VAL}(8) - \text{VAL}(7)]$$

[0064] The absolute gradients GRAD(1) to GRAD(8) are shown graphically at 47 in the chart 48 shown in Figure 7b. The microcontroller 18 (Figure 5) processes the absolute gradients to find the position of the image bar 40 (Figure 7a) having the largest associated gradient value. For the example shown in Figure 7b, the absolute
10 gradient 47f is the largest gradient, corresponding to the sixth image bar 40f.

[0065] It will be noted that the position of the first reference point 34 may not necessarily be in the image bar 40 with the highest gradient. It could at least theoretically be in the image bar 40 up from that one (where the bumper edge 32
15 appears domed) or in the image bar down from that one (where the bumper edge 32 appears dished). In the image 25 shown in Figure 7a it does happen to be in the image bar 40 with the highest gradient however.

[0066] The microcontroller 18 then selects a second, narrower search window, shown at 49 in Figure 9a and divides it into 8 vertically stacked bars 50 (shown
20 individually at 50a-50h). The position of the second search window 49 is selected based on which image bar 40 (Figure 7a) in the first search window 38 had the largest gradient (ie. the sixth image bar 40f in the example shown in the figures). In the embodiment shown, the second search window 49 (Figure 9a) is preferably positioned to ensure capture of the first reference point 34 somewhere within the image bars 50b-
25 50g. In the present embodiment, the microcontroller 18 positions the top of the second search window 49 the equivalent of the height of two image bars 40 from Figure 7a (ie. a total of 40 pixel rows) up from the bottom of the image bar 40f (represented in Figure 9a at 51). The second search window 49 is 64 pixels rows

high, and so the second search window 49 extends 24 pixel rows below the bottom of the image bar 40f (Figure 7a).

[0067] The absolute gradient calculations and analysis are performed on the second search window 49 to find which image bar 50 has the highest associated gradient. The resulting gradients are shown at 52 (and individually at 52a-52h), in the chart in Figure 9b. As can be seen, the absolute gradient shown at 52c is the highest in the chart in Figure 9b, and is associated with the image bar 50c in Figure 9a.

[0068] The microcontroller 18 selects a third search window shown at 54 in Figure 10a, which is 240 pixels wide x 32 pixels high. The position of the third search window 54 is based on the position of the image bar 50c (Figure 9a). The position of the top of the third search window 54 is selected to be the equivalent of the height of two image bars 50 from Figure 9a (ie. 16 pixel rows) up from the bottom of the image bar 50b.

[0069] The microcontroller 18 divides the third search window 54 (Figure 10a) into 8 vertically stacked image bars 55, (shown individually at 55a-55h), each of which is 4 pixels high, and performs the absolute gradient calculations thereon. The resulting gradient chart is shown at 56 in Figure 10b. The individual gradient shown at 57c, which is associated with the third image bar, shown at 58c in Figure 10a, is the highest gradient in the chart.

[0070] The microcontroller 18 selects a fourth search window 60 (Figure 11a), which is 240 pixels wide x 16 pixels high, based on the position of image bar 55c (Figure 10a). The top of the fourth search window 60 is selected to be 2 x height of the image bars 55 (ie. $2 \times 4 = 8$ pixels) upwards from the bottom of the image bar 55c (Figure 10a).

[0071] The microcontroller 18 divides the fourth search window 60 (Figure 11a) into 8 vertically stacked image bars 61, each of which is 2 pixels high, and performs the absolute gradient calculations on the fourth search window 60. The resulting gradient chart is shown at 62 in Figure 11b. The absolute gradient shown at

64e, which is associated with the fifth image bar, shown at 61e in Figure 11a, is the highest gradient in the chart.

[0072] The microcontroller 18 selects a fifth search window 66 (Figure 12a) which is 240 pixels wide x 8 pixels high, based on which image bar 61 (Figure 11a) had the largest gradient (ie. the fifth image bar 61e). The top of the fifth search window 66 is 2 x height of the image bars 61 (ie. $2 \times 2 = 4$ pixels) upwards from the bottom of the image bar 61e.

[0073] The microcontroller 18 divides the fifth search window 66 into 8 vertically stacked image bars 67, each of which is 1 pixel high, and performs the absolute gradient calculations thereon. The resulting gradient chart is shown at 68 in Figure 12b. The absolute gradient shown at 69d, which is associated with the fourth horizontal image bar, shown at 67d in Figure 12a, is the highest gradient in the chart. The vertical pixel position of the image bar 67d is determined by the microcontroller 18 to be the vertical pixel position of the first reference point 34.

[0074] To determine the horizontal position of the first reference point 34, the microcontroller 18 (Figure 5) selects a region of interest 70 (Figure 13a) and scans it for the presence of the bumper edge 32. The region of interest 70 may be about 240 pixels wide by 16 pixels high. The region of interest 70 is centered horizontally in the image 25. Vertically, the region of interest 70 extends from 12 pixels above the determined vertical position of the first reference point 34, to 4 pixels below the determined vertical position of the first reference point 34.

[0075] The microcontroller 18 selects two first search windows 1000a and 1000b that are each 1 pixel wide x 8 pixels high, thereby forming a single compound search window that is 1 pixel wide x 16 pixels high. The microcontroller 18 obtains the greyscale values of each pixel in the two search windows 1000a and 1000b and determines which pixel out of the 16 pixels has the highest associated gradient. That pixel represents the bumper edge 32, and so the microcontroller 18 stores the position of that pixel in memory. The microcontroller 18 then selects two second search windows 1008a and 1008b which are 8 pixels to the right of the first search windows

1000a and 1000b. The microcontroller 18 determines the greyscale values of each pixel in the two windows 1008a and 1008b and determines the pixel with the highest gradient among them and stores its position in memory. The microcontroller 18 then selects another pair of search windows 1016a and 1016b and determines the pixel
5 with the highest gradient among them. The microcontroller 18 continues along the region of interest 70 selecting vertically stacked pairs of search windows at 8 pixel intervals.

[0076] The chart shown in Figure 13b illustrates the pixel position values stored by the microcontroller 18 across 32 pairs of search windows. The pixel
10 position values may be stored in a vector having a dimension of 1x32. The data contained in the vector may be conditioned and validated as follows, to account for problems that can arise, such as a change in the ambient environment seen by the camera 11 after the pre-processing module 102 (Figure 5) has approved the cycle to proceed with detecting the reference point 34.

15 **[0077]** The conditioning of the data in the vector takes place based on one or more rules that are applied to the data. A first rule is that the pixel position value of the first element in the vector, (ie. the pixel position value corresponding to the search windows 1000a and 1000b), cannot be larger than that of the second element in the vector (ie. cannot be larger than the pixel position value of the subsequent search
20 windows 1008a and 1008b). If it is larger, its value is reduced to be the same as that of the second element. A second rule is that, if the pixel position value of any particular vector element (referred to as vector element (i) where i corresponds to its position in the vector) is less than that of the immediately preceding vector element (ie. vector element (i-1)) and that of the immediately proceeding vector element (ie.
25 vector element (i+1)) and if the immediately preceding and immediately proceeding vector elements have the same pixel position value as each other, then the pixel position value of the particular vector element (ie. vector element (i) is changed to match that of the immediately preceding and immediately proceeding vector elements. A third rule is that if the pixel position value of any particular vector (ie.

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vector element (i) is greater than that of vector element (i+1) and is greater than that of vector element (i-1), and if the pixel position value of vector element (i+1) is greater than that of vector element (i-1), then the pixel position value of vector element (i) is changed to match that of vector element (i+1). A fourth rule is similar to the third rule. If the pixel position value of any particular vector (ie. vector element (i)) is greater than that of vector element (i+1) and is greater than that of vector element (i-1), and if the pixel position value of vector element (i-1) is greater than that of vector element (i+1), then the pixel position value of vector element (i) is changed to match that of vector element (i-1). A fifth rule is that if the pixel position value of the last vector element, (ie. vector element (32)), is greater than that of the preceding vector element (ie. vector element (31)), then the value of the last vector element is changed to match that of the preceding vector element. A sixth rule is that if the highest pixel position value stored in the vector appears less than 4 times in the vector, then the pixel position values of the associated vector elements are changed to match the second highest pixel position value stored in the vector. It will be noted that the particular rules described above are based on knowledge a priori of what general shape the bumper 202 should have in the image 25. It will be noted that the aforementioned rules are intended as exemplary. It is alternatively possible for the system to apply a different set of rules to condition the values in the vector. It will be noted that the rules may change depending on the vehicle model on which the camera 11 is installed.

[0078] Once the pixel position values stored in the vector are conditioned using the aforementioned rules, the values are tested to determine if they are considered valid to determine whether the reference point detection can continue or whether to abandon the reference point detection cycle until some other time. The conditions checked to determine whether the values are valid may include one or more of the following 5 questions:

1. Is the highest pixel position value between 11 and 13?

2. Does the highest pixel position value appear at least 3 times in the vector?

3. Is the number of times that the highest pixel position value appears between the first occurrence of it (at vector element (i)) and the last occurrence of it (at vector element (j)), greater than or equal to $(j-i) / 2$, where i and j are the values of the positions in the vector corresponding to the first and last occurrences of the highest pixel position value respectively?

4. Are the pixel position values of the first and last vector elements less than highest pixel position value present in the vector?

5. Are the pixel position values of all the vector elements between the first and last occurrences of the highest pixel position values greater than or equal to 11?

For the above questions, any 'no' answer may be referred to as a glitch. A variable (which is given the name 'count1') stores the number of 'rising glitches' (ie. glitches where the pixel position value of vector element (i) > the pixel position value of the vector element (i+1)).

A variable (which is given the name 'count2') stores the number of 'falling glitches' (ie. glitches where the pixel position value of vector element (i) < the pixel position value of the vector element (i+1)).

A variable (which is given the name 'count3') stores the number of 'flat glitches' (glitches where the pixel position value of vector element (i) is not equal to highest pixel position value).

If $\text{Count1} + \text{count2} + \text{count3} \Rightarrow 5$ then the reference point detection cycle is abandoned.

[0079] For any glitch, the glitch amplitude corresponds to how far past the given limit the pixel position value was for any given vector element. If there are more than 3 glitches having a glitch amplitude of more than 3, then the reference point detection cycle is abandoned.

[0080] If the reference point detection cycle has not been abandoned based on the aforementioned questions, the vector is passed through a 5 taps median filter. The filter goes through each vector element (i), and determines a median value for a group of 5 vector elements centered on element (i) (ie. the group of vector elements consisting of vector element (i-2), vector element (i-1), vector element (i), vector element (i+1) and vector element (i+2)). The filter then changes the value of the vector element (i) to the determined median value. It will be understood that the 5 taps median filter is an optional procedure. It is possible for the vector to be used as is without being passed through the filter. It is alternatively possible for the vector to be filtered in any other suitable way.

[0081] As can be seen in the chart, the pixel position value (in this case a value of 14) is the same for the search window pairs 1096a, 1096b to 1160a, 1160b (Figure 13a), and so the actual horizontal position of the first reference point 34 is somewhere between them.

[0082] First, the microcontroller 18 determines whether the same pixel position value (in this case a value of 14) is found for search window pairs 1095a, 1095b to 1089a, 1089b that are immediately to the left of the pair 1096a, 1096b, and for search window pairs 1161a, 1161b to 1167a, 1167b that are immediately to the right of the pair 1160a, 1160b.

[0083] Referring to Figure 14a, the microcontroller 18 determines in the exemplary embodiment, that the pixel position value remains at 14 for all the search window pairs 1095a, 1095b to 1089a, 1089b. Referring to Figure 14b, the microcontroller 18 determines that the pixel position value drops to 13 at the first search window pair 1161a, 1161b to the right of the window pair 1160a, 1160b. Accordingly, no further pixel position values are necessary to be determined to the right of that.

[0084] To determine the horizontal position of the first reference point 34, the microcontroller 18 determines the middle (horizontally) between the leftmost search window pair and the rightmost search window pair that have the same peak pixel

position value. In the particular example shown, the leftmost search window pair is shown at 1089a, 1089b, and the rightmost search window pair is shown at 1160a, 1160b. The two window pairs are 71 pixels apart horizontally. The middle of the peak is therefore 36 pixels to the right of search window pair 1089a, 1089b, and is
5 determined by the microcontroller 18 to be the horizontal position of the first reference point 34.

[0085] Referring to Figure 5, it will be noted that the above description provides one way of determining the vertical and horizontal positions of the first reference point 34. It is alternatively possible for the microcontroller 18 to determine
10 the position of the first reference point 34 by any other suitable method, using the statistical data that is provided by the imager microcontroller 16b and without access to the image 25 itself. Additionally, the algorithm itself may be different for different models of vehicle and different cameras, and for different locations for the camera. For example, certain portions of the algorithm may change depending on whether the
15 vehicle bumper 202 appears dished or domed in images 25 taken by the camera 11. Also certain portions of the algorithm will change depending on the location of the camera 11 in the vehicle 10, since the particular structure on which the reference point is positioned and the associated background, changes depending on whether the camera 11 is side mounted camera or a rear mounted camera.

[0086] Once the horizontal and vertical pixel values of the first reference point 34 are determined, the database 110 (Figure 5) of calibration data is updated. These values are simply added to the database 110 if the database 110 isn't full. If the database 110 is already full, these values are used to overwrite the oldest reference point data contained in the database 110. The database 110 may be configured to hold
25 data from 50 reference point detections cycles. Each record of the database 110 contains the horizontal and vertical pixel positions of the first reference point 34, the date and time and optionally other data. In total each record may take up 16 bytes of memory, including ten bytes for the horizontal and vertical pixel positions, the date

and time, and 6 bytes for additional data. Thus, the total amount of memory required for 50 records is 800 bytes.

[0087] The post-processing module 106 is used to determine whether or not to adjust the positions of the overlays 26 based on the database 110 of calibration data.

5 In one embodiment, the post-processing module 106 is itself made up of two modules including a statistics analysis module 300 and a decision logic module 302. The statistics analysis module 300 determines the mean values, the variance for the horizontal and vertical pixel positions in the database 110, the median of the pixel position data and the mode for the pixel position data, and the variance for the time of
10 day data in the database 110.

[0088] Based on the results of the analysis conducted by the statistics analysis module 300, the decision logic module 106 determines whether or not to adjust the positions of the overlays 26. The actual adjustment that is made to the positions of the overlays 26 may be selected based on the entirety of the pixel position data in the
15 database 110, not just on the currently determined pixel position values. It will be noted that the vertical and horizontal pixel positions of the overlays 26 are independent from one another. As such, it is possible that one coordinate (eg. the vertical position) of the overlays 26 may be adjusted, while the other coordinate (eg. the horizontal position) of the overlays 26 is not adjusted. For example, in one
20 embodiment, if the amount of horizontal offset between the horizontal position detected for the reference point 34 and the horizontal position currently used by the camera 11 is greater than 4 pixels, then the horizontal position used by the camera 11 for the overlays 26 will be updated. Separately, if the amount of vertical offset between the vertical position detected for the reference point 34 and the vertical
25 position currently used by the camera 11 is greater than 2 pixels, then the vertical position used by the camera 11 for the overlays 26 will be updated.

[0089] If the microcontroller 18 determines that the amount of overall offset exceeds a selected amount, the microcontroller 18 notifies the vehicle driver that the camera 11 may be too far outside of its intended operating position and may require

servicing. This can be especially useful in situations where the camera 11 has become seriously misaligned with the vehicle 10 or if the lens 20 has become significantly misaligned with the imager 16 due, for example, to a collision wherein damage to the camera 11 or vehicle tailgate has occurred and has gone unnoticed.

5 **[0090]** The optional rotational offset detection module 108 (Figure 5) detects if the camera 11 has any rotational offset so that this can be taken into account when adjusting the positions of the overlays 26.

[0091] If the lens 20 (Figure 2) and image sensor 16a were perfectly oriented, the curved line corresponding to the bumper's edge 32 (Figure 17) in the image 25
10 would appear as shown at 400 in the rotation angle search window shown at 402 in Figure 17, and would intersect with the side edges of the search window 402 at a height H1 on both the left and right sides. In situations where the lens 20 (Figure 2) and the image sensor 16a are not oriented perfectly, the curved line corresponding to the bumper's edge 32 appears skewed as shown at 404 and would intersect with the
15 side edges of the search window 402 at different heights, as shown by H2a and H2b. The width of the search window 402 is shown at W.

[0092] The rotation angle search window 402 may be selected based on the detected vertical position of the first reference point 34 (Figure 7a), and may extend a selected number of pixels above and below the vertical position of the first reference
20 point 34, based on whether the bumper 202 appears domed or dished in the image 25 (this would be programmed into the module 108 during vehicle assembly). The width of the rotation angle search window 402 may be selected to ensure bumper edge 32 leaves the search window 402 at a point along the sides of the search window 402, and not on the top or bottom of the search window 402.

25 **[0093]** To determine the pixel positions at which the bumper edge 32 leaves the search window 402, the microcontroller 18 selects a first compound search window that is 1 pixel wide by 16 pixels high, and is thus made up of a pair of 1 pixel by 8 pixel search windows, along the left side of the search window 402. The pixel position representing the highest gradient in that compound search window is the

pixel position at which the bumper edge leaves the left side of the search window 402. Similarly, the microcontroller 18 selects a second compound search window on the right side of the search window 402 and determines the pixel with the highest associated gradient to determine the pixel position at which the bumper edge leaves
5 the right side of the search window 402. By applying the following formula the rotation angle of the camera 11 can be determined:

$$\text{Camera angle} = \arctan((H2b-H2a)/W)$$

[0094] Once the camera angle is determined, it can be compared to historical data for the camera angle that is optionally contained in the database 110 and can be
10 used to adjust the positions of the overlays 26. As can be seen in Figure 17, the rotation angle can affect the horizontal (and the vertical to a lesser extent) position of the extremum of the curve representing the bumper edge 32. Thus, a rotational change in the camera could cause the linear offset detection module 104 (Figure 5) to find a horizontal shift in the camera's position. By detecting the rotation angle of the
15 camera 11, any contribution made by the rotation angle to the determined linear offset can be adjusted for.

[0095] Optionally, the camera 11 may be capable of being calibrated at night. To provide this capability, the camera 11 may include a NIR (near infra-red) LED (shown at 11a in Figure 1) that is activated when the reference point detection and the
20 camera angle detection are being carried out. For efficiency the NIR LED 11a may have a narrow illumination pattern and may be directed generally towards the bumper's edge 32 (Figure 1). The reflection from the bumper 202 will be stronger than the reflection from the background, thereby providing relatively high contrast at the bumper's edge 32.

[0096] It will be noted that the calibration of the camera 11 can be carried out without the need to add any structure to the vehicle than is already present thereon (ie. without the need to add targets or other calibration-specific structure to the vehicle
25 10), and without the need for additional structure or modification to the camera 11 itself.

[0097] In addition to calibrating the camera 11 periodically after the vehicle 10 has been bought, the above-described camera 11 can be calibrated as described prior to the vehicle 10 leaving the assembly plant. Additionally or alternatively, the camera 11 can be calibrated when the vehicle 10 is at the dealer, prior to being sold or
5 during a servicing of the vehicle 10. For example, a technician/service person at a vehicle dealer can send a signal to the camera 11 to enter a 'service mode' to facilitate its use in calibrating itself.

[0098] While the above description constitutes a plurality of embodiments of the present invention, it will be appreciated that the present invention is susceptible to
10 further modification and change without departing from the fair meaning of the accompanying claims.

CLAIMS:

1. A camera for a vehicle, comprising:
 - a lens positioned to capture a view behind a vehicle, wherein the view includes
 - 5 a portion of the bumper of the vehicle;
 - an imager including an image sensor and an imager microcontroller, wherein the image sensor is positioned to receive images from the lens; and
 - a camera microcontroller configured to control the application of an overlay to the images, wherein the camera microcontroller is configured to receive data from the
 - 10 imager microcontroller relating to bars of pixels on the image sensor, wherein the microcontroller is further configured to detect a reference point in the images using the data and is configured to determine an offset amount with which to shift the overlay on the images.
- 15 2. A camera as claimed in claim 1, wherein the imager microcontroller is configured to transmit the images to an in-vehicle display via an analog signal.
3. A camera as claimed in claim 1, wherein the camera microcontroller is configured to detect the reference point iteratively using data from the imager
- 20 microcontroller relating to successively smaller bars of pixels on the image sensor.
4. A camera as claimed in claim 1, wherein the camera microcontroller is configured to detect the vertical pixel position of the reference point using data from vertically stacked bars of pixels on the image sensor.
- 25 5. A camera as claimed in claim 4, wherein the camera microcontroller is configured to detect the horizontal pixel position of the reference point using data from horizontally stacked bars of pixels on the image sensor.

6. A camera as claimed in claim 1, wherein the reference point corresponds to a point on the edge of the bumper of the vehicle.
7. A camera as claimed in claim 6, wherein the edge of the bumper of the vehicle
5 appears as a curved line in the images received by the imager and wherein the reference point is an extremum on the curved line.
8. A camera as claimed in claim 1, wherein, prior to detecting the reference point, the camera microcontroller determines whether there is sufficient contrast in the
10 images.
9. A camera as claimed in claim 8, wherein the camera microcontroller selects bars of pixels in the images and compares brightness values of the pixels and variances in brightness between adjacent pixels within each bar to determine if there
15 is sufficient contrast in the images.
10. A camera as claimed in claim 1, wherein the camera microcontroller is configured to determine the rotation angle of the camera and to adjust the offset amount based on the rotation angle.
20
11. A camera as claimed in claim 10, wherein the camera microcontroller is configured to determine the rotation angle of the camera and to adjust the position of the overlay rotationally based on the detected rotation angle.
- 25 12. A camera as claimed in claim 1, further comprising a near-infrared LED configured to emit near-infrared light on the portion of the bumper of the vehicle.
13. A method of calibrating a vehicular camera installed in a vehicle wherein the camera has an imager and a camera microcontroller, comprising:

- a) determining whether the contrast in images received by the imager is beyond a selected threshold value;
- b) searching for a reference point in the images depending on the result of step a) using the camera microcontroller; and
- 5 c) adjusting the position of an overlay applied by the microcontroller to the images depending on the result of step b).
14. A method as claimed in claim 13, wherein step b) includes:
- d) selecting a search window within the images;
- 10 e) dividing the search window into a plurality of bars, wherein each bar corresponds to a plurality of pixels on the imager;
- f) receiving data relating to brightness levels of the bars; and
- g) detecting the position of the reference point based on changes in brightness levels from bar to bar.
- 15
15. A method as claimed in claim 14, wherein the search window selected in step d) is a vertical position search window and wherein step b) further includes:
- h) selecting a rotation angle detection search window;
- i) searching for the positions of a plurality of rotation angle reference
- 20 points; and
- j) determining whether to adjust the position of the overlay rotationally based on the results of step i).

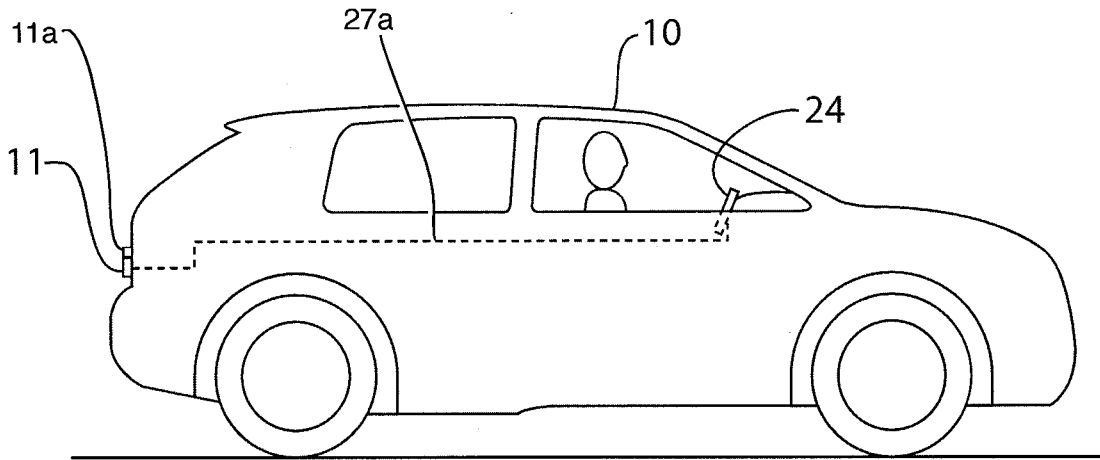


FIG. 1

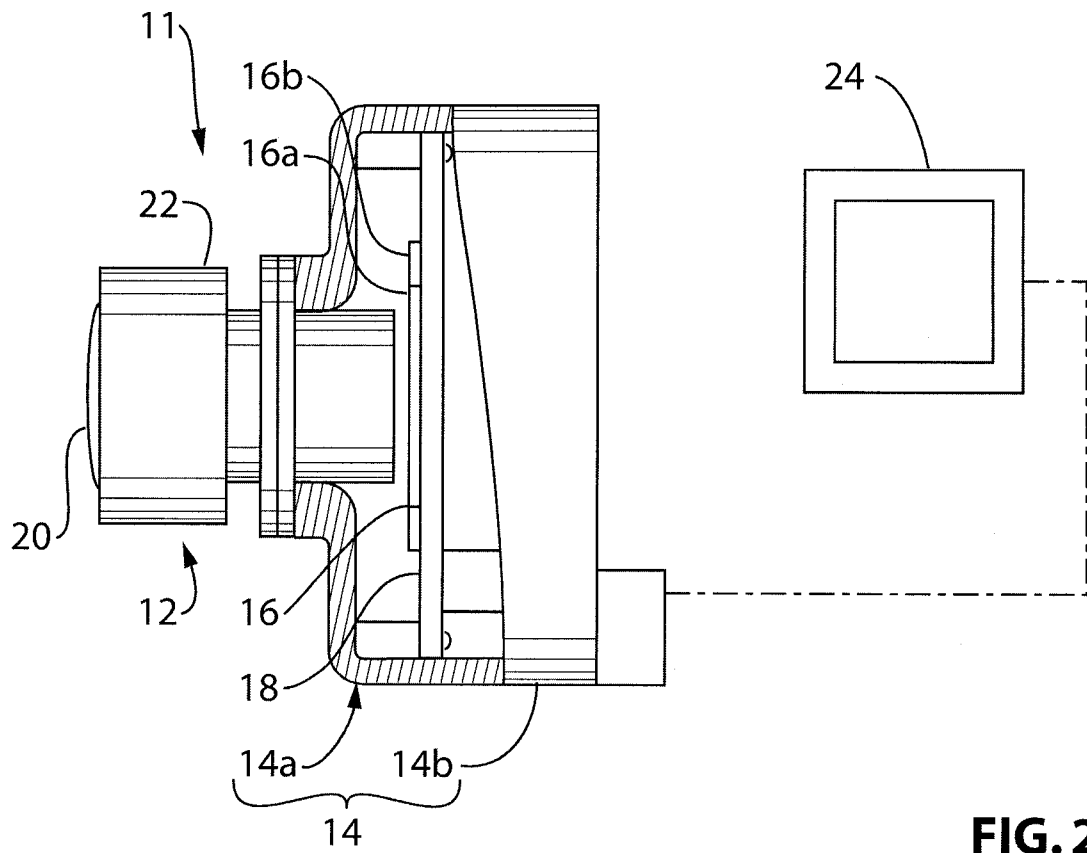


FIG. 2

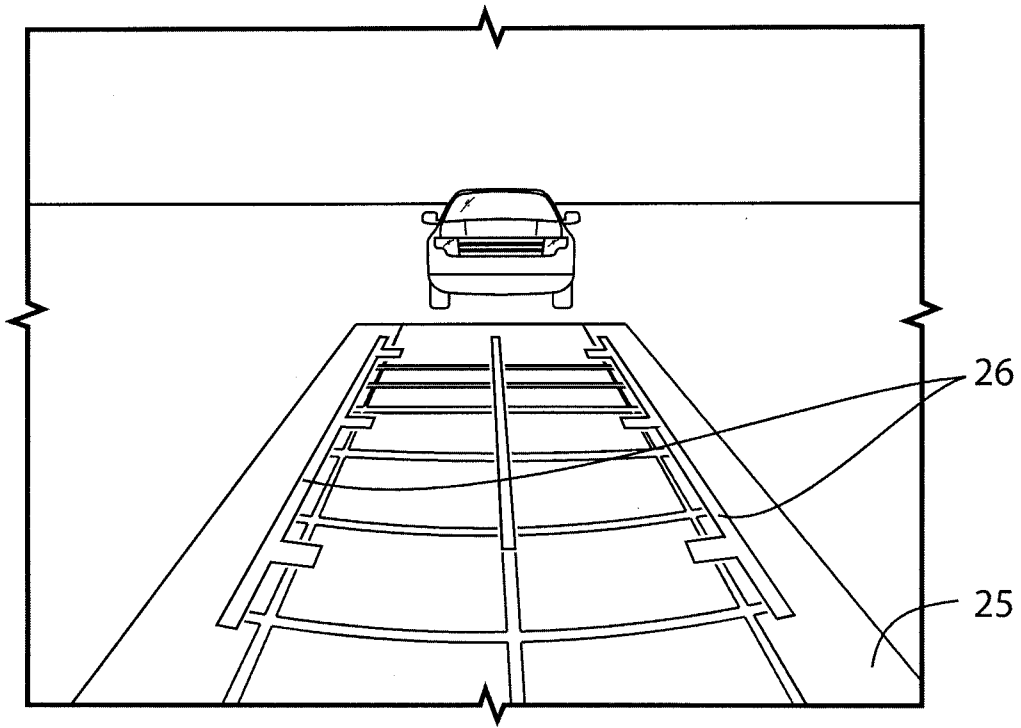


FIG. 3

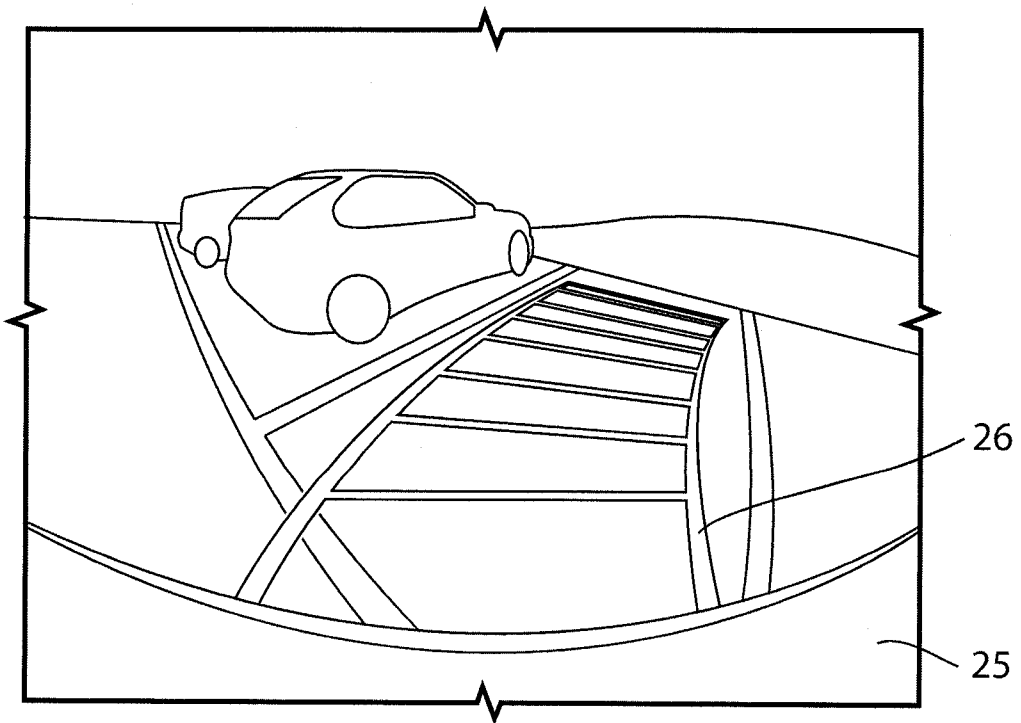


FIG. 4

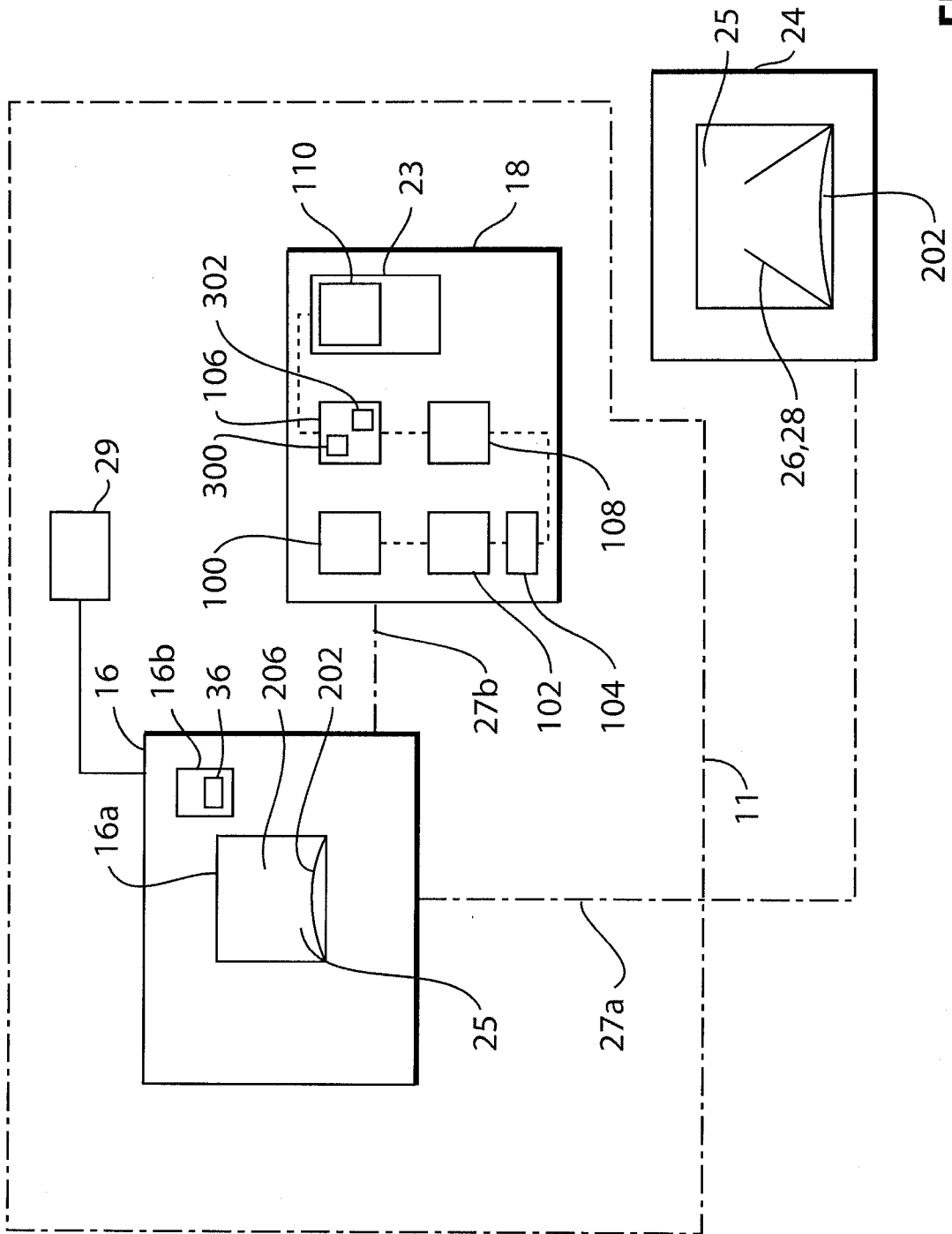


FIG. 5

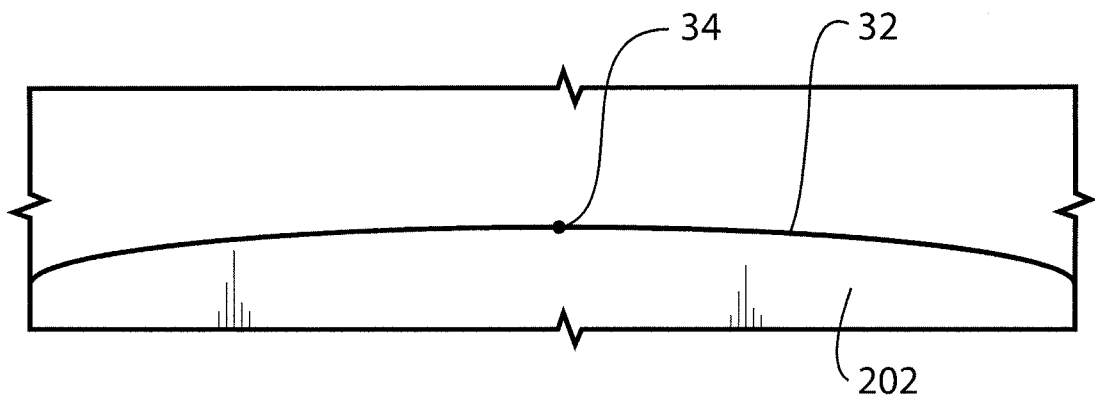


FIG. 6a

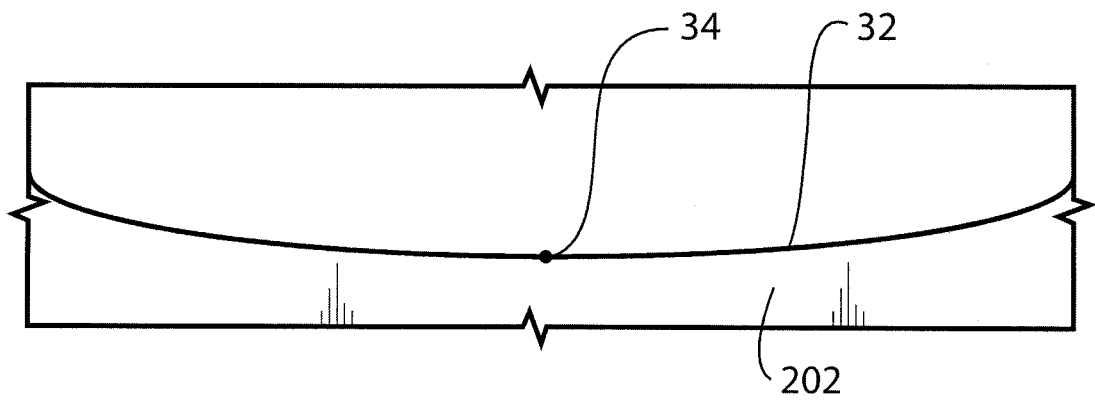


FIG. 6b

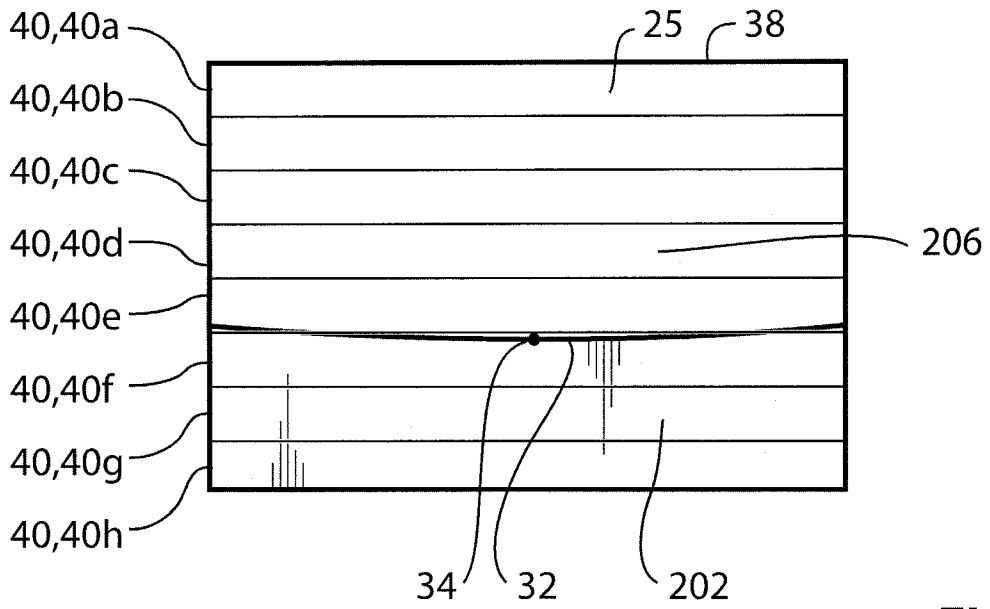


FIG. 7a

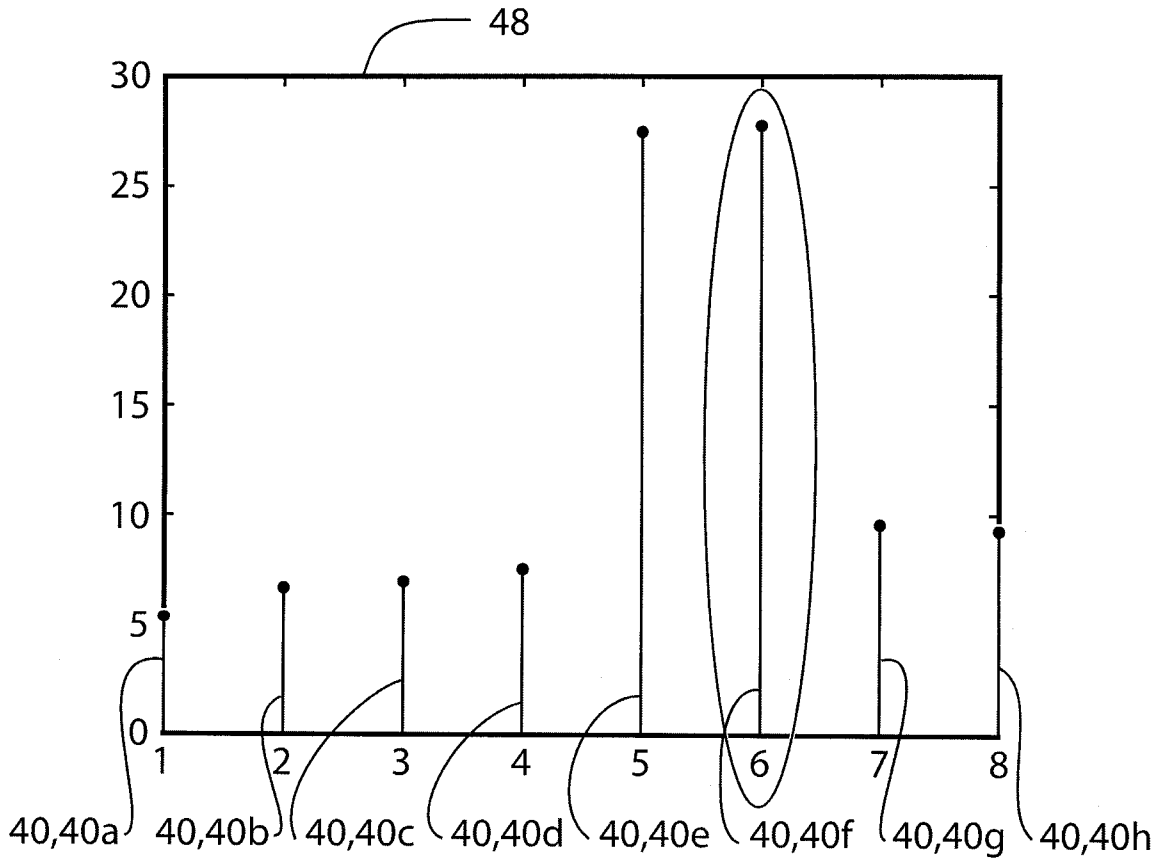


FIG. 7b

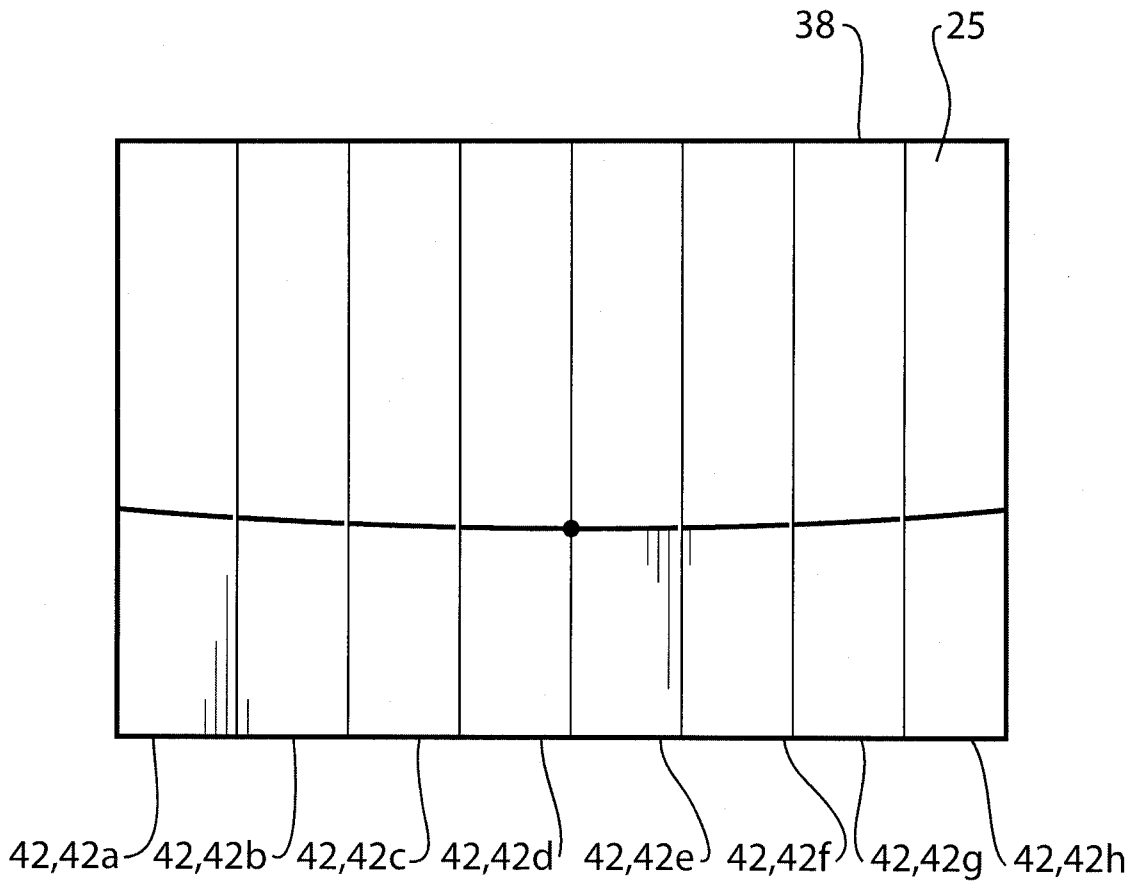


FIG. 8

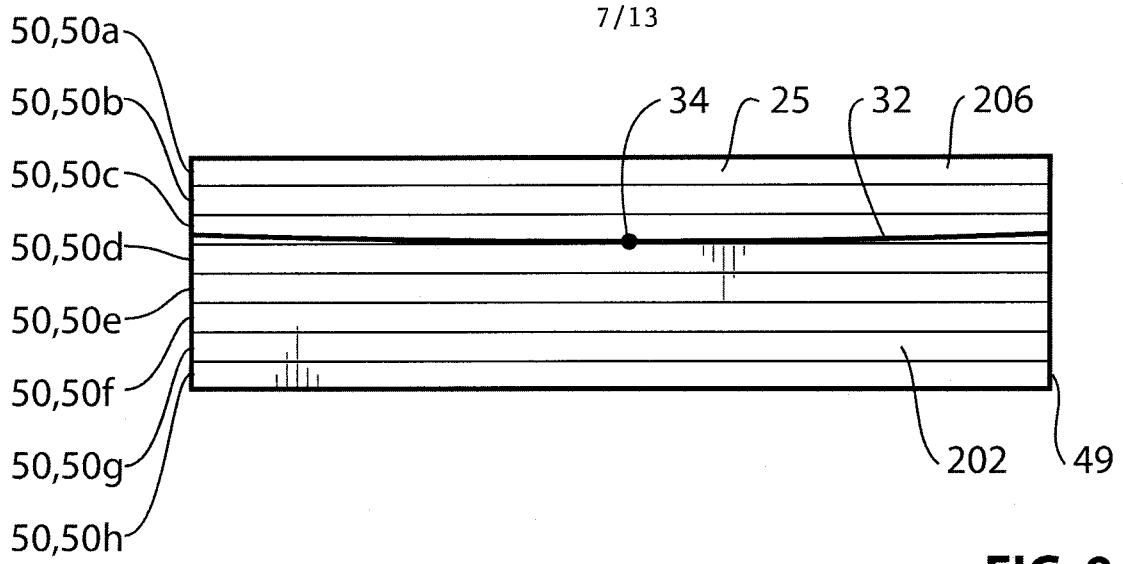


FIG. 9a

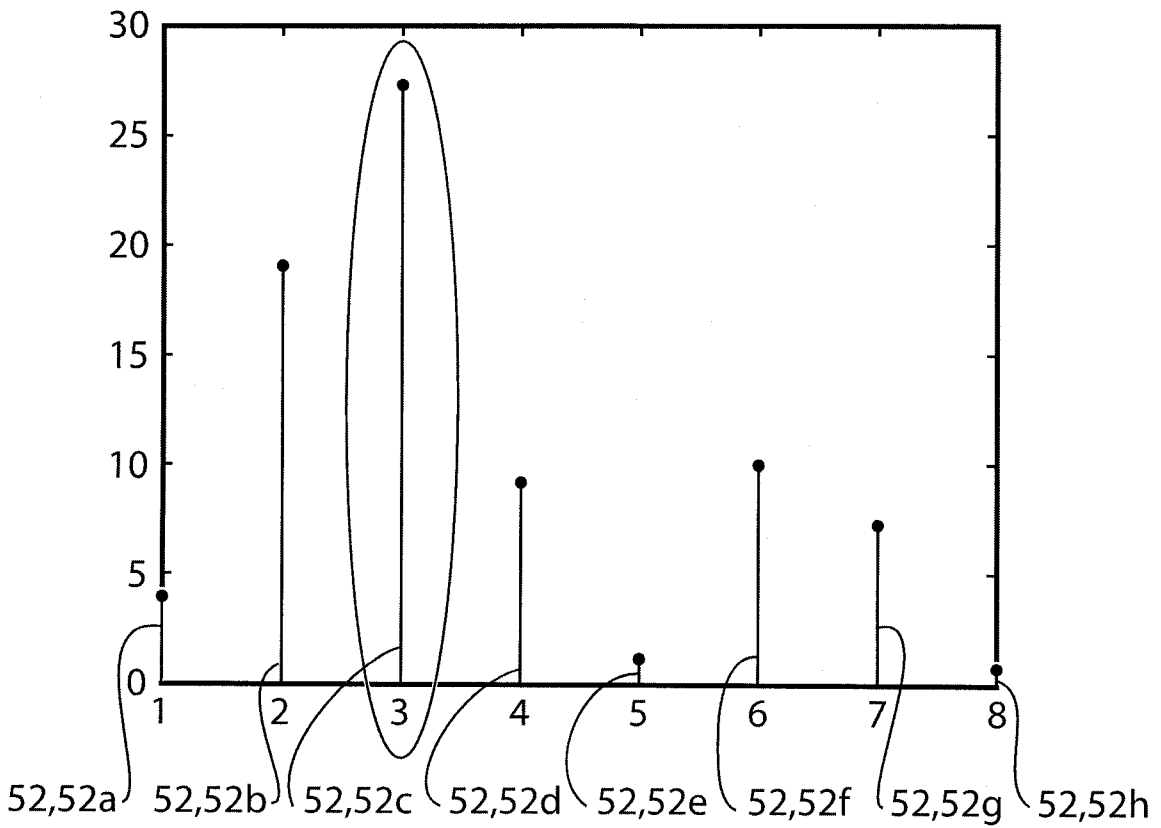


FIG. 9b

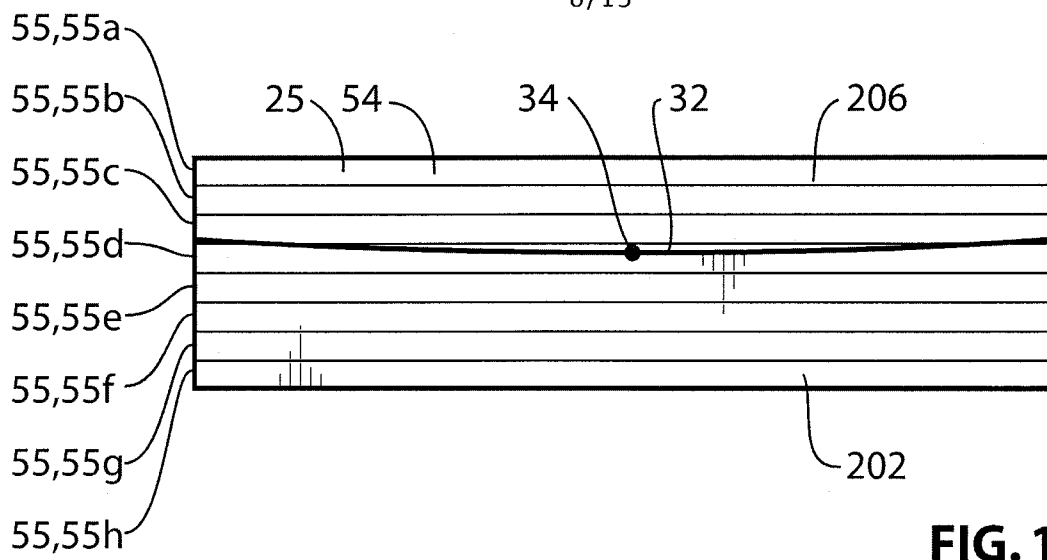


FIG. 10a

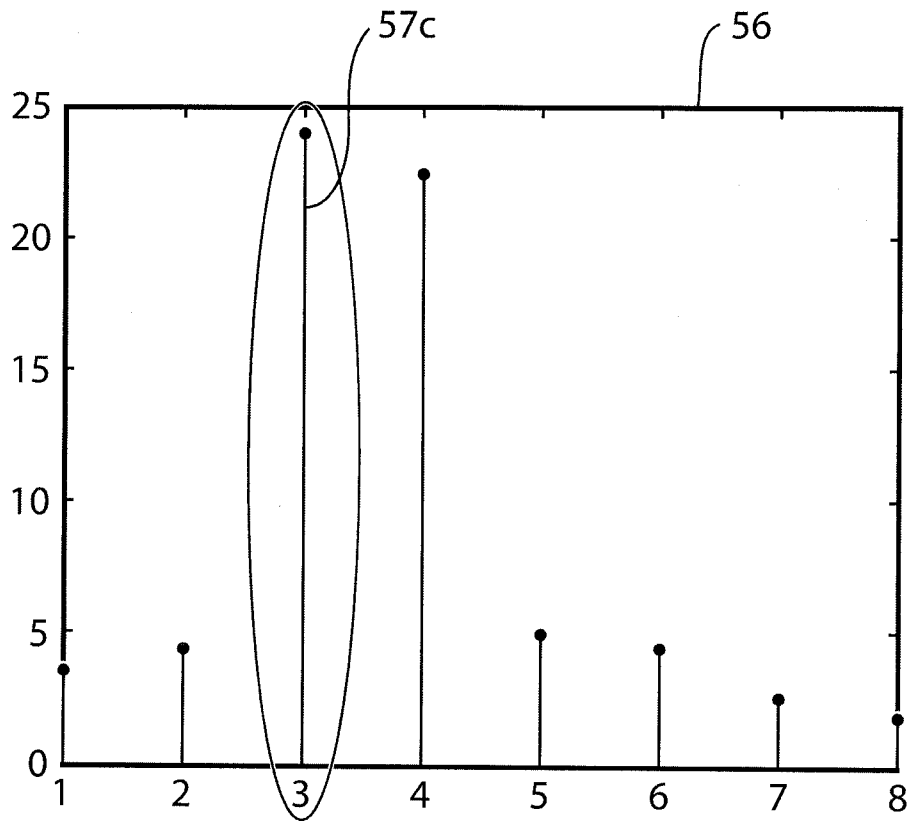


FIG. 10b

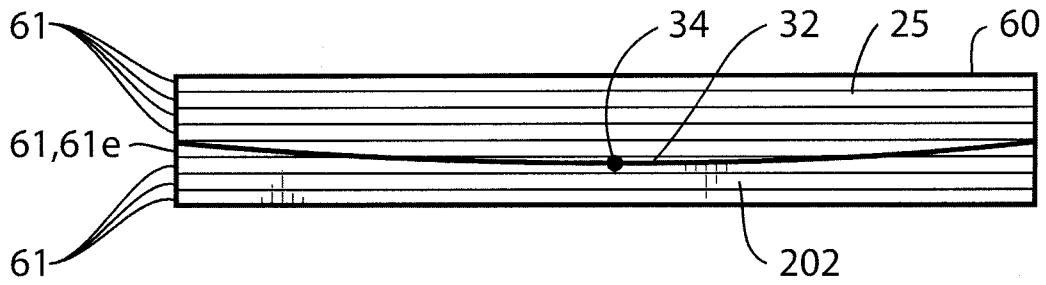


FIG. 11a

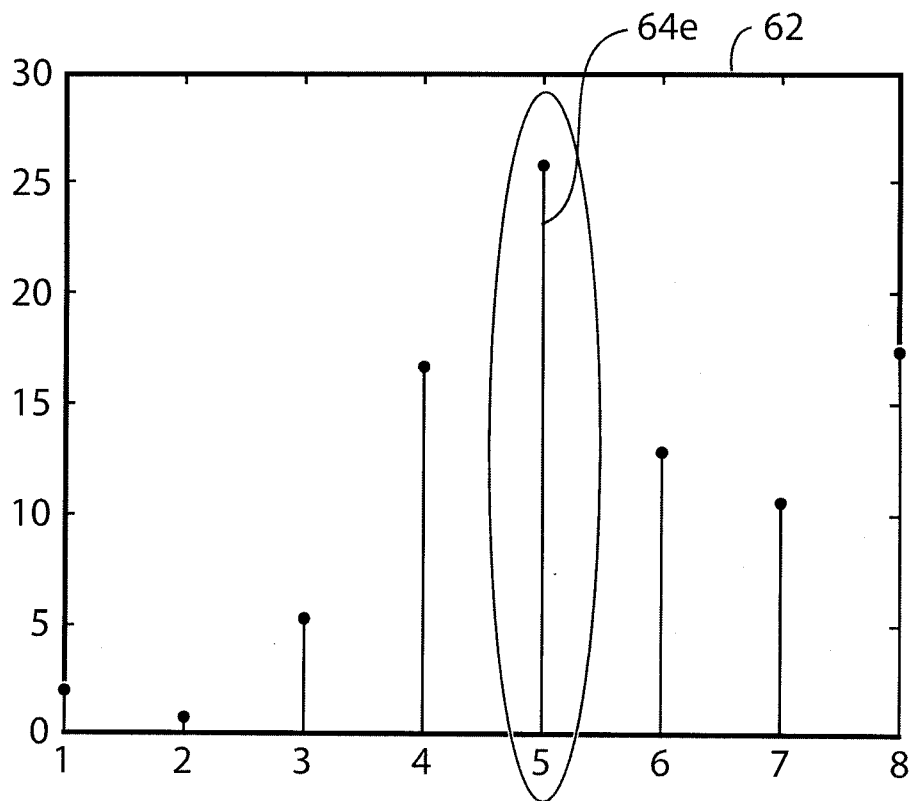


FIG. 11b

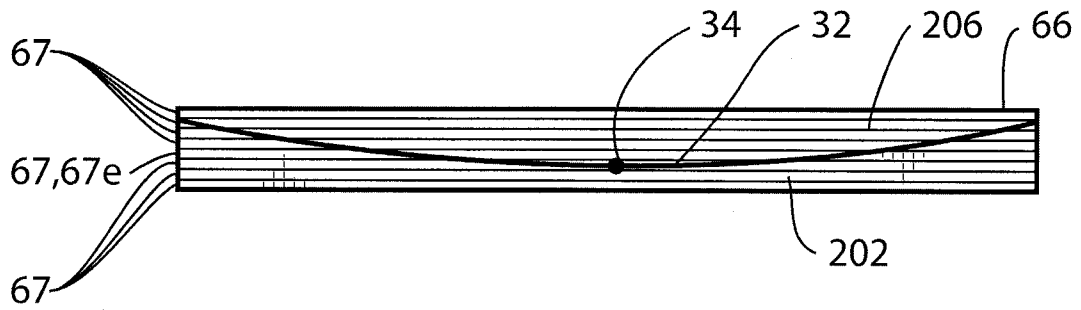


FIG. 12a

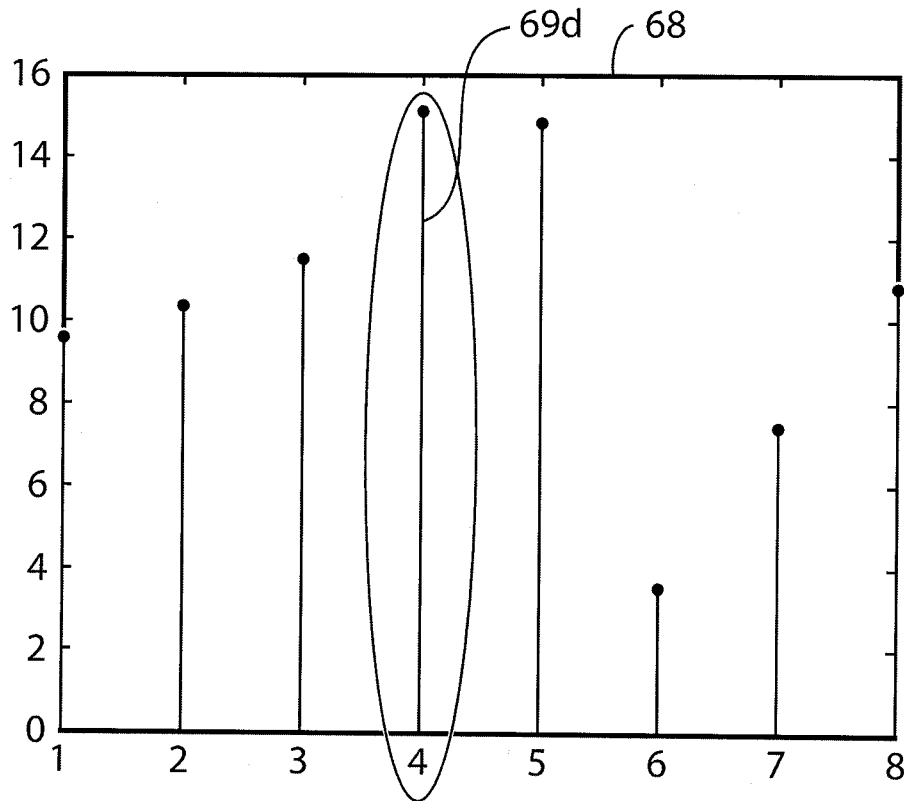


FIG. 12b

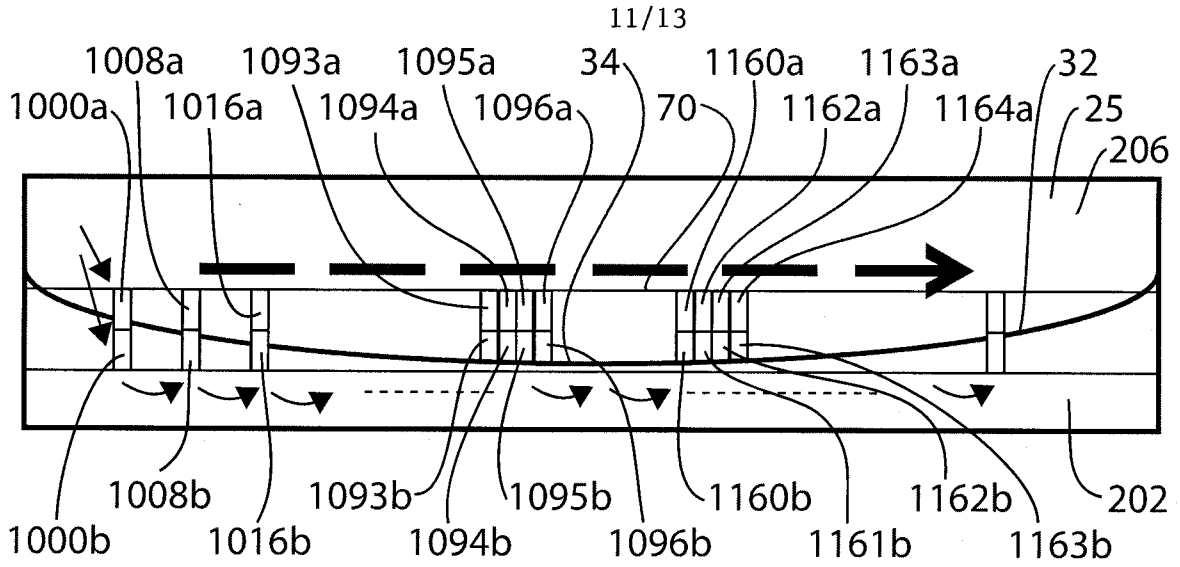


FIG. 13a

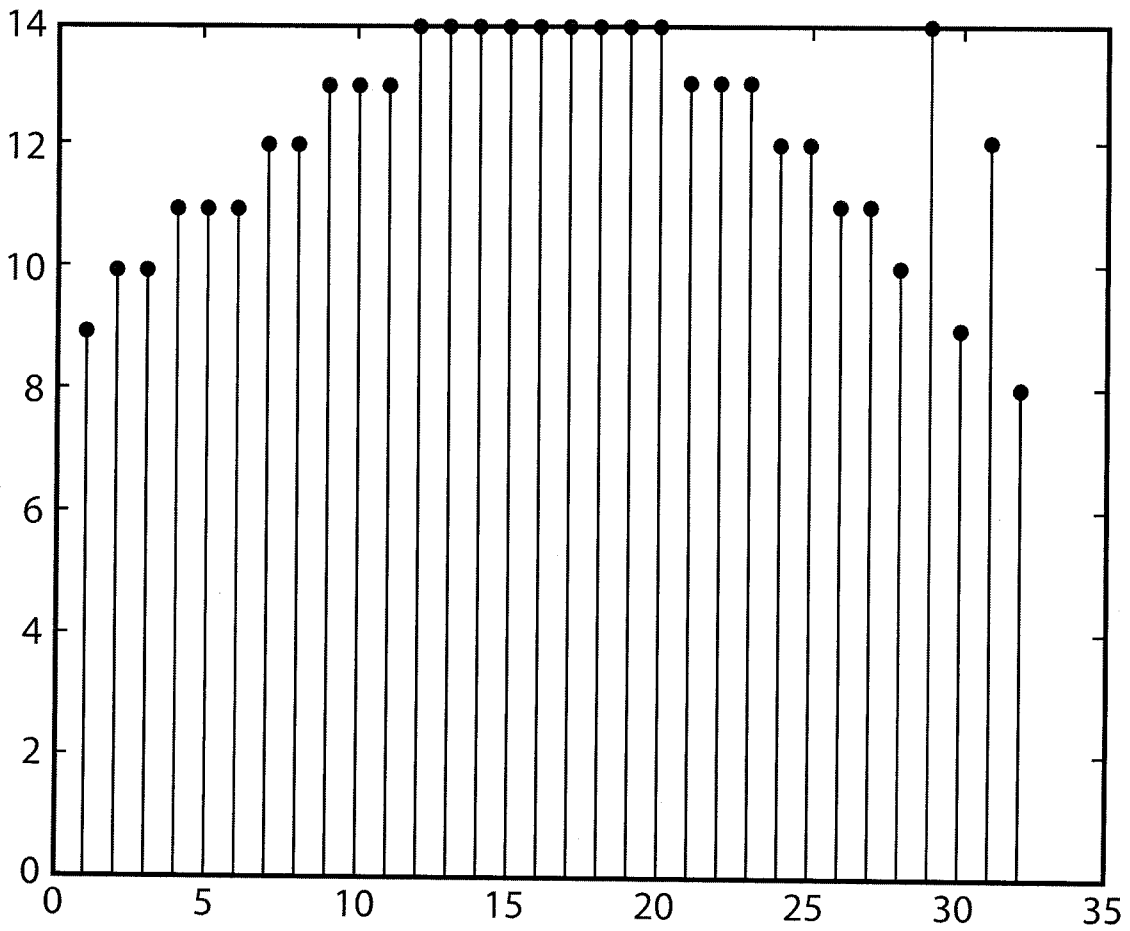


FIG. 13b

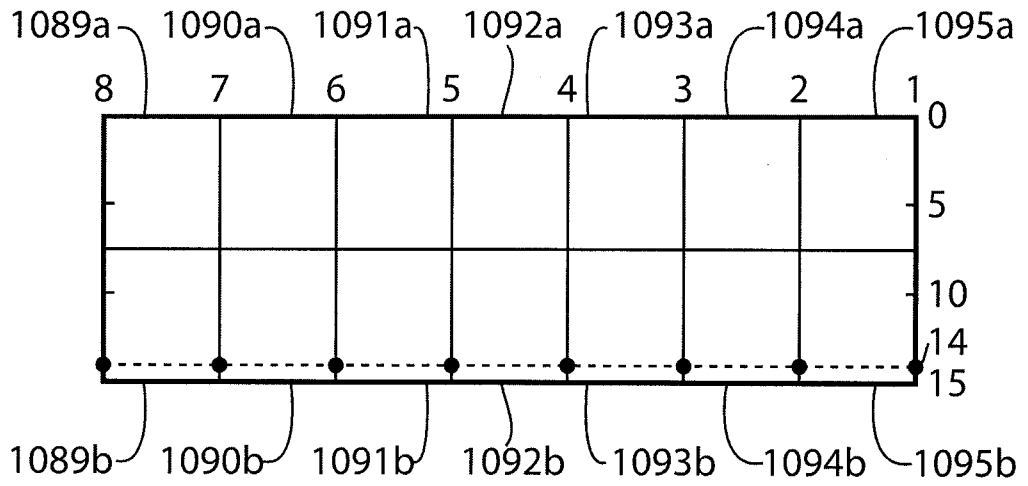


FIG. 14a

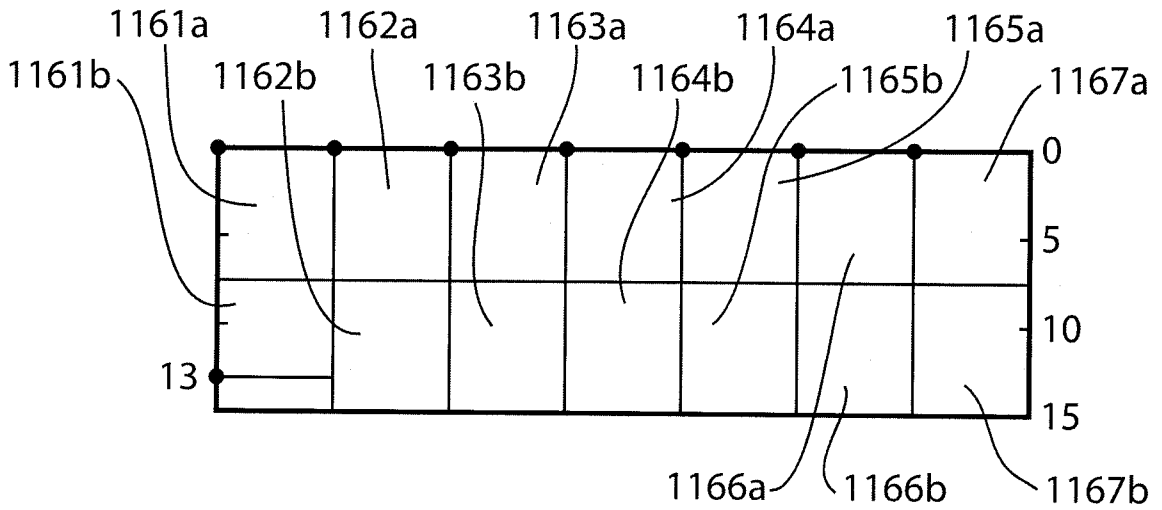


FIG. 14b

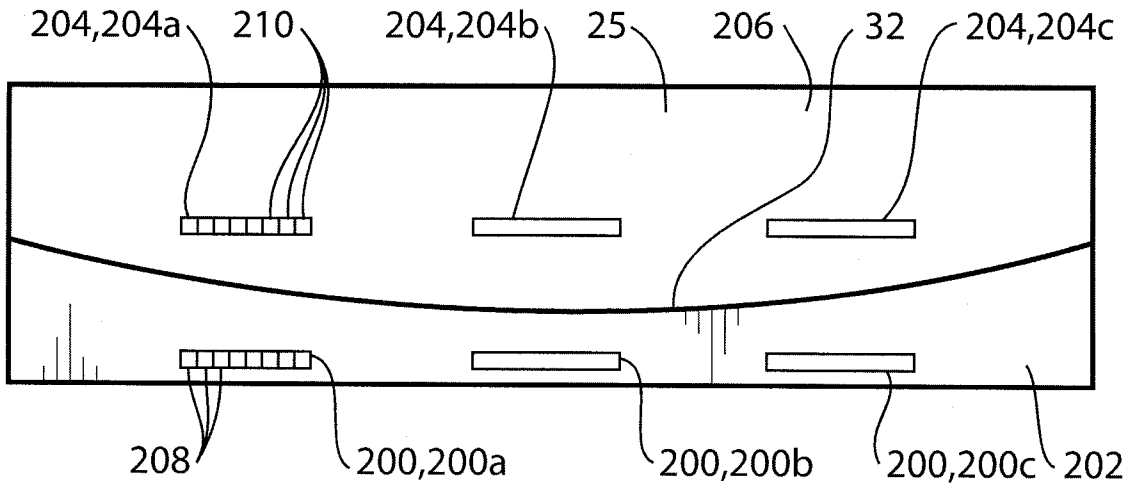


FIG. 15

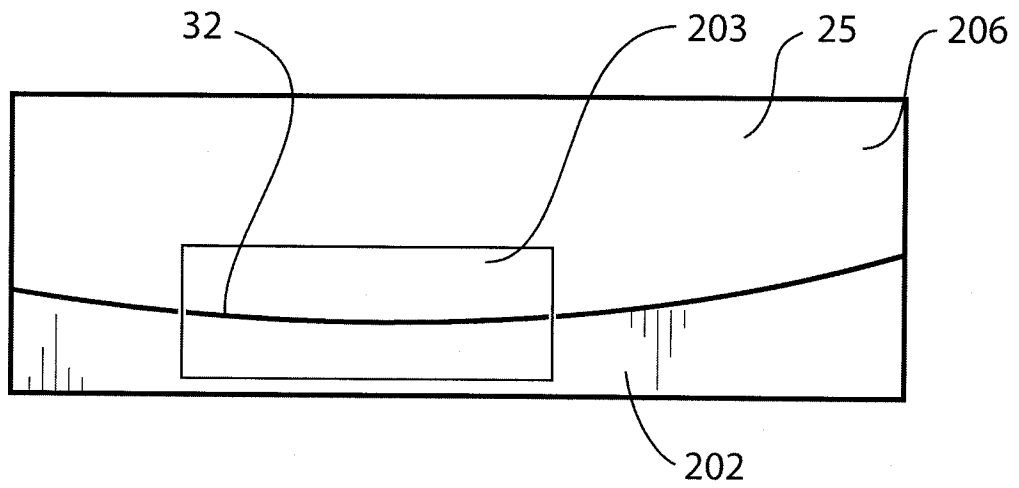


FIG. 16

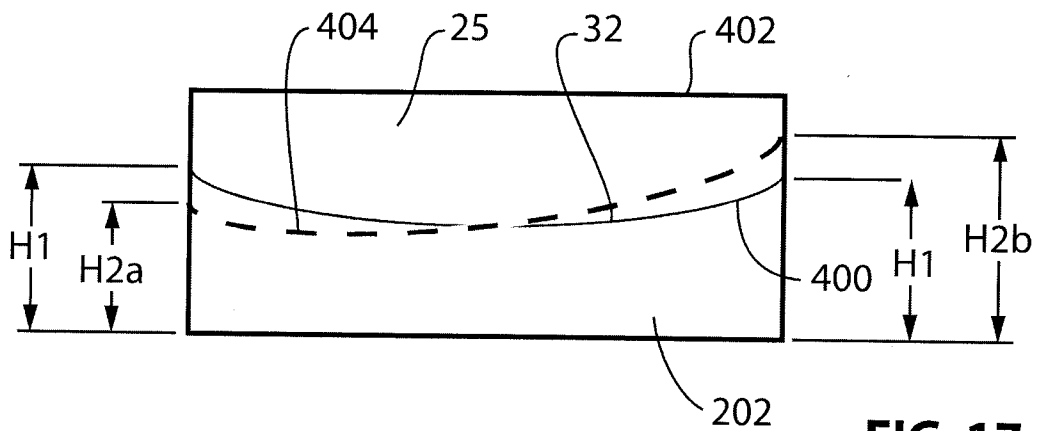


FIG. 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2011/000048

| <p>A. CLASSIFICATION OF SUBJECT MATTER IPC: B60R 11/04 (2006.01) , H04N 7/18 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC</p> | | | | | | | | | | | | | | | | | | | | | | | |
|--|---|---|-----------|--|-----------------------|--------|---|------------------------------|------|---|--------------------|---|--|----|---|---|----|---|--|------|---|---|------|
| <p>B. FIELDS SEARCHED</p> <p>Minimum documentation searched (classification system followed by classification symbols) IPC: B60R 11/04 (2006.01), H04N 7/18 (2006.01)</p> <p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched</p> <p>Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used) Databases: EPOQUE (Epodoc, English Full-text), Canadian Patents Database, IEEEExplore, Google Keywords: calibrate, camera, vehicle/auto, image, pixel, misaligned, bumper/rear/behind, contrast/brightness, reference/calibration/detection point, horizontal/vertical, threshold, offset/rotation angle, near-infrared LED</p> | | | | | | | | | | | | | | | | | | | | | | | |
| <p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X Y</td> <td>JP 2007256030 A (OKUYAMA) 4 October 2007 (04-10-2007) *automated machine translation to English of the whole document*</td> <td>1, 2, 6, 7, 10, 11 12, 13</td> </tr> <tr> <td>P, X</td> <td>US 2010/0245592 A1 (INUI et al.) 30 September 2010 (30-09-2010) *abstract; paragraphs [0006]-[0024], [0046-0050], [0081]-[0122]; fig. 8*</td> <td>1, 2, 6, 7, 10, 11</td> </tr> <tr> <td>Y</td> <td>US 6 768 509 B1 (BRADSKI et al.) 27 July 2004 (27-07-2004) *abstract*</td> <td>13</td> </tr> <tr> <td>Y</td> <td>JP 9150670 A (SASAKI) 10 June 1997 (10-06-1997) *automated machine translation to English of the abstract; fig. 1*</td> <td>12</td> </tr> <tr> <td>A</td> <td>DE 102007043905 A1 (EHLGEN) 29 May 2008 (29-05-2008) *automated machine translation to English of the whole document*</td> <td>1-15</td> </tr> <tr> <td>A</td> <td>JP 2005077107 A (SATONAKA) 24 March 2005 (24-03-2005) *automated machine translation to English of the whole document*</td> <td>1-15</td> </tr> </tbody> </table> | | | Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. | X Y | JP 2007256030 A (OKUYAMA) 4 October 2007 (04-10-2007) *automated machine translation to English of the whole document* | 1, 2, 6, 7, 10, 11 12, 13 | P, X | US 2010/0245592 A1 (INUI et al.) 30 September 2010 (30-09-2010) *abstract; paragraphs [0006]-[0024], [0046-0050], [0081]-[0122]; fig. 8* | 1, 2, 6, 7, 10, 11 | Y | US 6 768 509 B1 (BRADSKI et al.) 27 July 2004 (27-07-2004) *abstract* | 13 | Y | JP 9150670 A (SASAKI) 10 June 1997 (10-06-1997) *automated machine translation to English of the abstract; fig. 1* | 12 | A | DE 102007043905 A1 (EHLGEN) 29 May 2008 (29-05-2008) *automated machine translation to English of the whole document* | 1-15 | A | JP 2005077107 A (SATONAKA) 24 March 2005 (24-03-2005) *automated machine translation to English of the whole document* | 1-15 |
| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. | | | | | | | | | | | | | | | | | | | | | |
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| <p><input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C.</p> | | <p><input checked="" type="checkbox"/> See patent family annex.</p> | | | | | | | | | | | | | | | | | | | | | |
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| <p>Date of the actual completion of the international search</p> <p>23 March 2011 (23-03-2011)</p> | <p>Date of mailing of the international search report</p> <p>6 April 2011 (06-04-2011)</p> | | | | | | | | | | | | | | | | | | | | | | |
| <p>Name and mailing address of the ISA/CA</p> <p>Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476</p> | <p>Authorized officer</p> <p>Daniela Savin (819) 934-4890</p> | | | | | | | | | | | | | | | | | | | | | | |

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