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(54) **SINGLE CAMERA SYSTEM AND METHOD FOR RANGE AND LATERAL POSITION MEASUREMENT OF A PRECEDING VEHICLE**

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See application file for complete search history.

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(57) **ABSTRACT**

A system for determining range and lateral position of a vehicle is provided. The system includes a camera and a processor. The camera is configured to view a region of interest including the vehicle and generate an electrical image of the region. The processor is in electrical communication with the camera to receive the electrical image. The processor analyzes the image by identifying a series of windows within the image each window corresponds to features of the vehicle at a different target range. For example, from the perspective of the camera the vehicle will appear larger when it is closer to the camera than if it is further away from the camera. Accordingly, each window is sized proportional to the vehicle as it would appear at each target range. The processor evaluates characteristics in the electrical image within each window to identify the vehicle. A score is determined indicating the likelihood that certain characteristics of the electrical image actually correspond to the vehicle and also that the vehicle is at target range for that window.

44 Claims, 4 Drawing Sheets
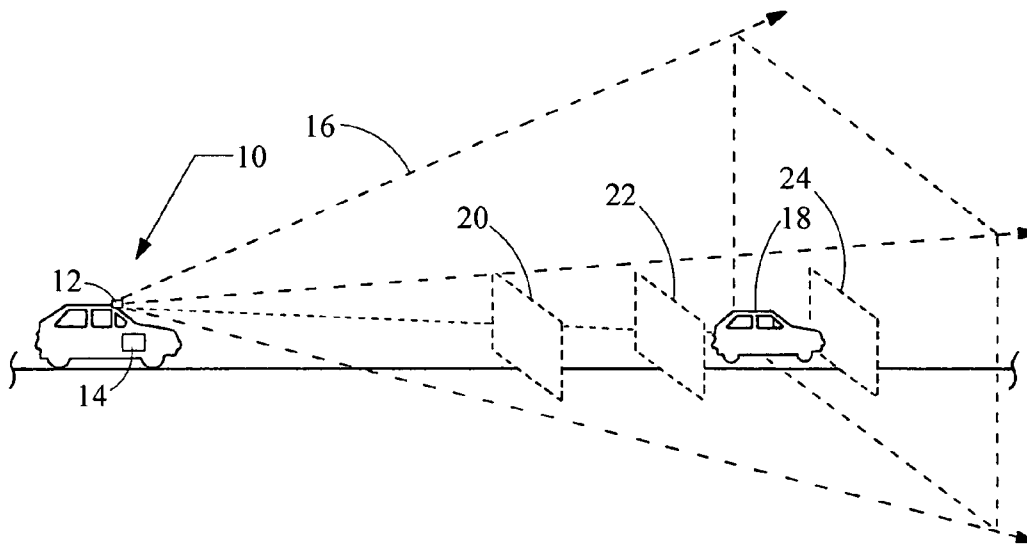
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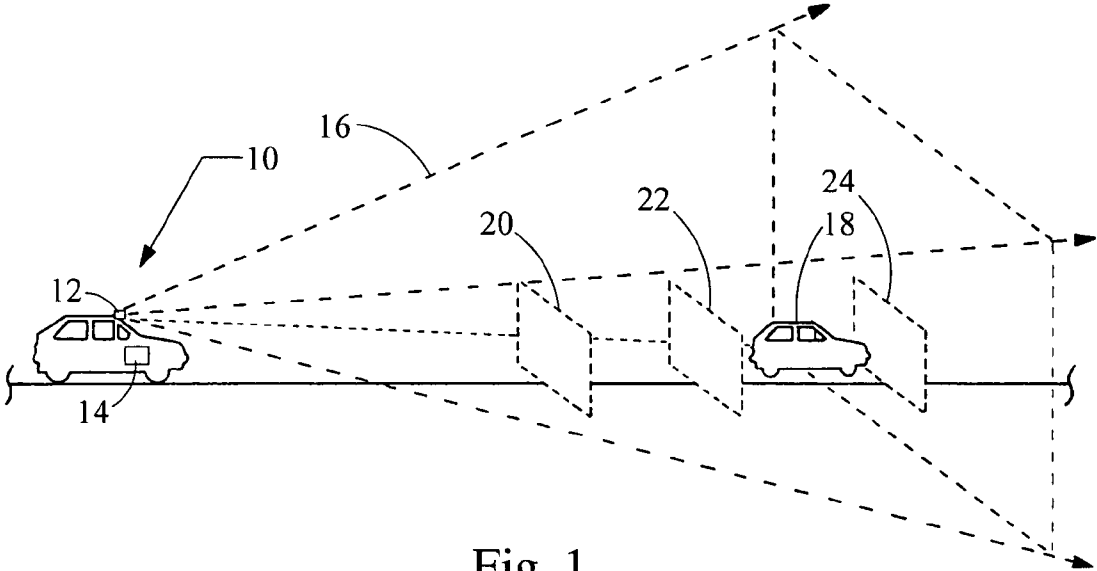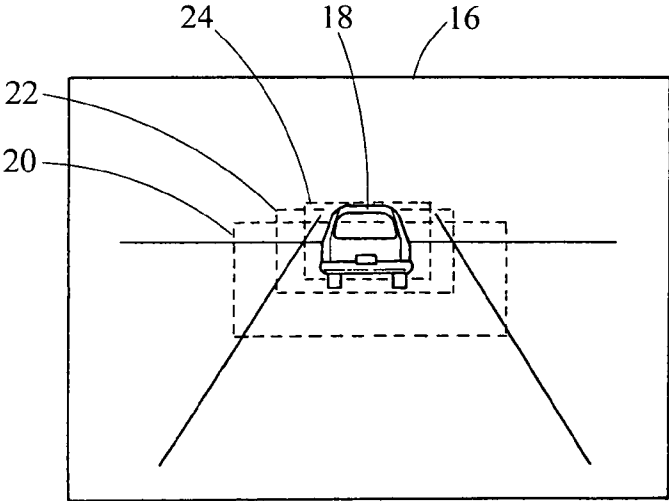U.S. Patent and Trademark Office Notice of Allowance, U.S. Appl. No. 11/049,502, Dated Nov. 13, 2008.
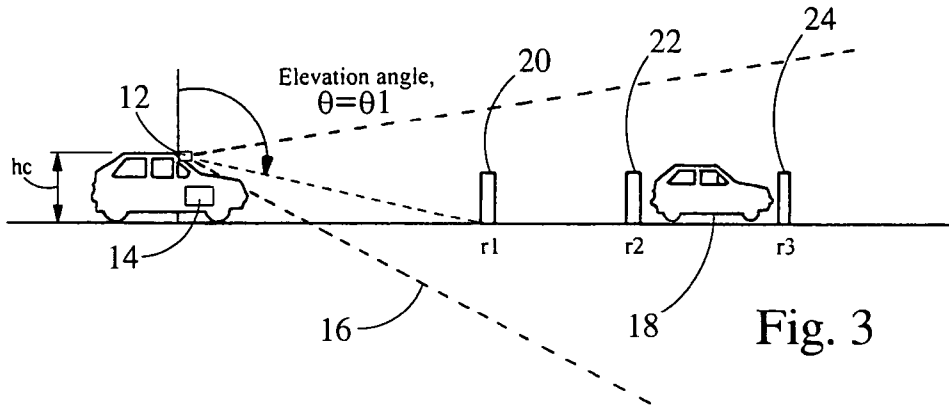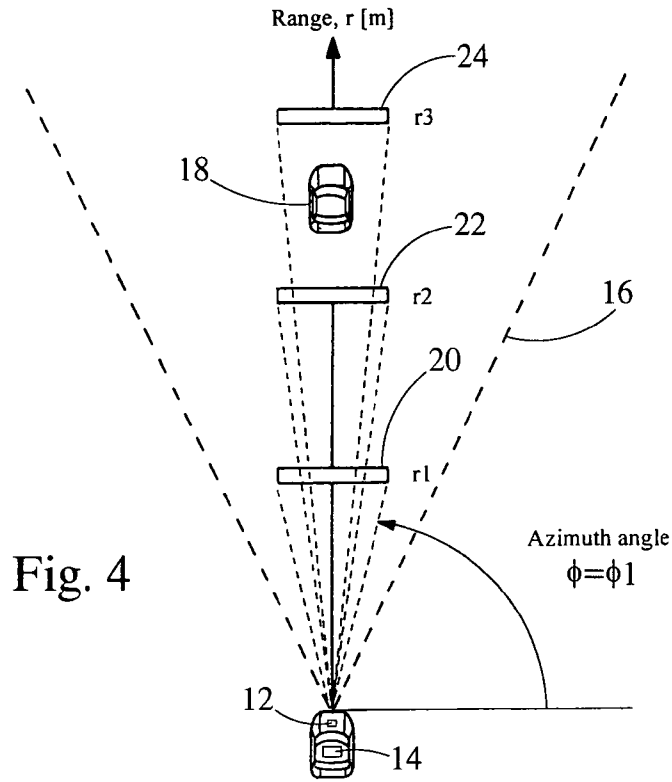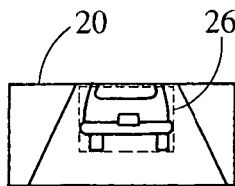
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Fig. 1

Fig. 2

Fig. 3
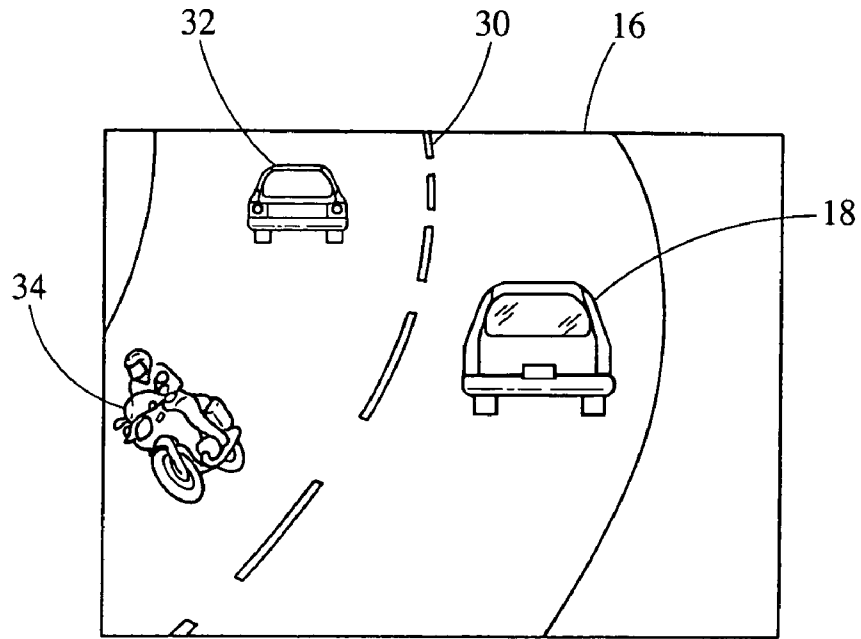

Fig. 4
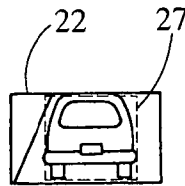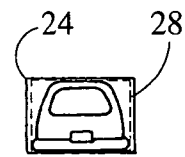
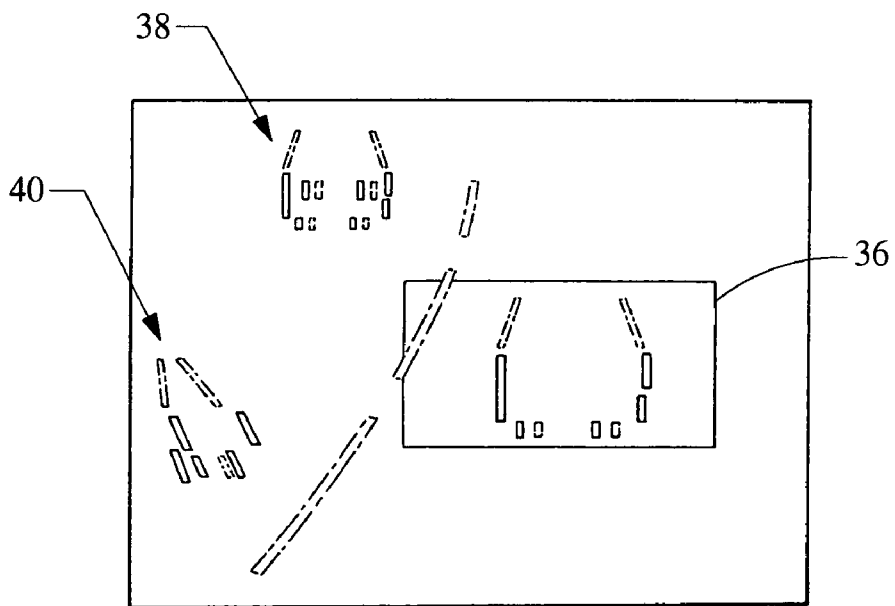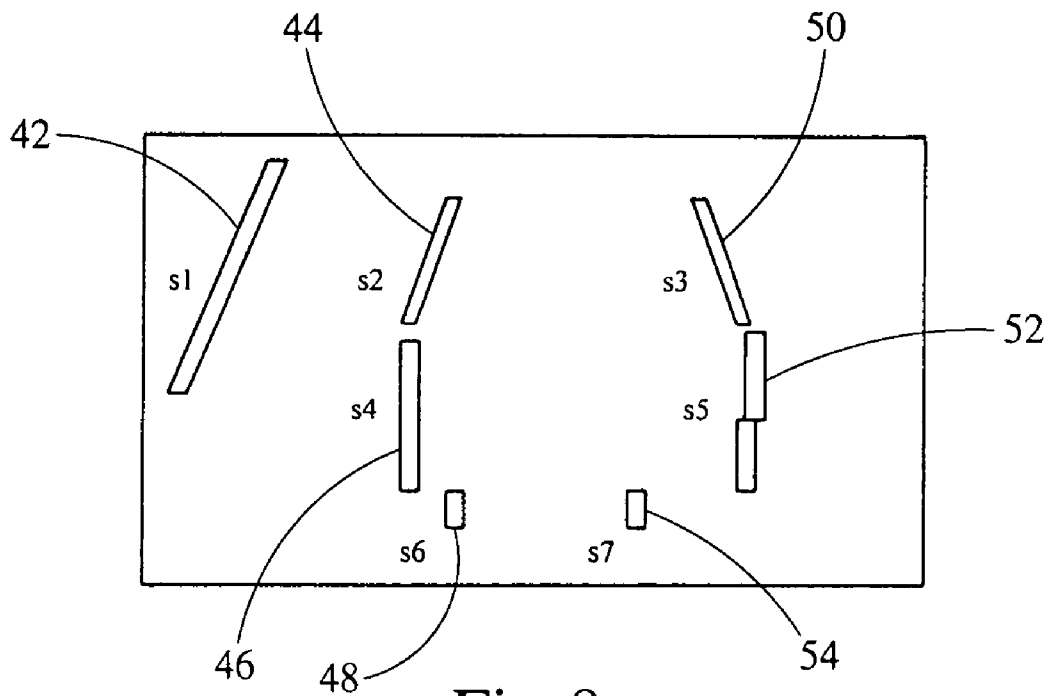Fig. 5A   Fig. 5B   Fig. 5C

Fig. 6

Fig. 7

Fig. 8
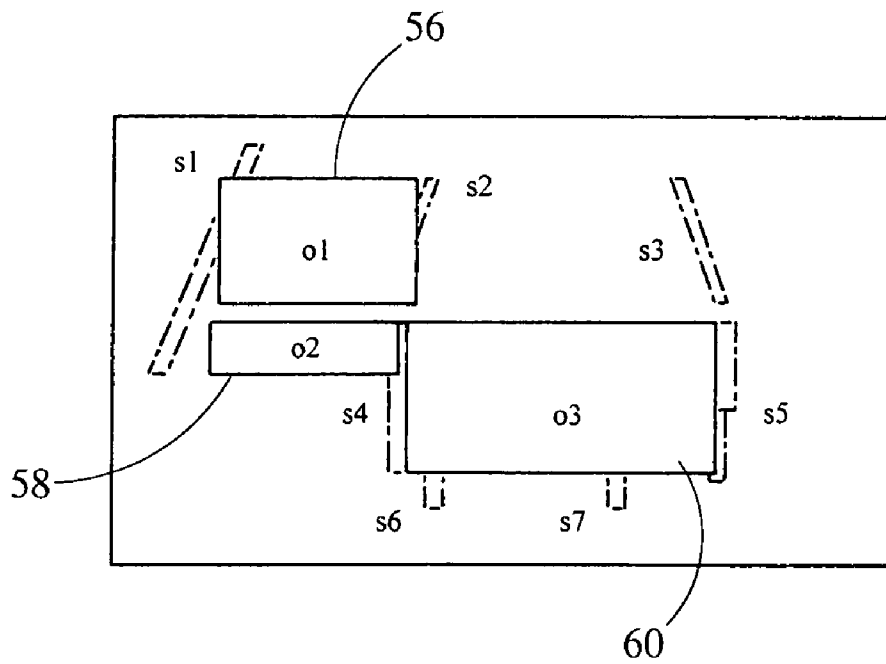
Fig. 9

SINGLE CAMERA SYSTEM AND METHOD FOR RANGE AND LATERAL POSITION MEASUREMENT OF A PRECEDING VEHICLE

BACKGROUND

1. Field of the Invention

The present invention generally relates to a system and method for range and lateral position measurement of a preceding vehicle.

2. Description of Related Art

Radar and stereo camera systems for adaptive cruise control (ACC), have been already introduced into the market. Recently, radar has been applied to for pre-crash safety systems and collision avoidance. Typically, the range and lateral position measurement of a preceding vehicle is accomplished utilizing radar and/or stereo camera systems. Radar systems can provide a very accurate range. However, millimeter wave type radar systems such as 77 Ghz systems are typically quite expensive. Laser radar is low cost but is not effective in adverse weather. Further, radar generally is not well suited to identify the object and give an accurate lateral position.

Stereo cameras can determine the range and identity of an object. However, these systems do not perform well in adverse weather and are typically difficult to manufacture due to the accurate alignment required between the two stereo cameras and requires two image processors.

In view of the above, it can be seen that conventional ACC systems typically do not have a high cost-performance ratio even though they may perform to the desired functional requirements. Further, it is apparent that there exists a need for an improved system and method for measuring the range and lateral position of the preceding vehicle.

SUMMARY

In satisfying the above need, as well as overcoming the enumerated drawbacks and other limitations of the related art, the present invention provides a system for determining range and lateral position of a vehicle. The primary components of the system include a single camera and a processor. The camera is configured to view a region of interest containing a preceding vehicle and generate an electrical image of the region. The processor is in electrical communication with the camera to receive the electrical image. To analyze the electrical image, the processor identifies a series of windows within the image, each window corresponding to a fixed physical size at a different target range. For example, from the perspective of the camera the vehicle will appear larger when it is closer to the camera than if it is further away from the camera. Accordingly, each window is sized proportionally in the image as it would appear to the camera at each target range. The processor evaluates characteristics of the electrical image within each window to identify the vehicle. For example, the size of the vehicle is compared to the size of the window to create a size ratio. A score is determined indicating the likelihood that certain characteristics of the electrical image actually correspond to the vehicle and also that the vehicle is at the target range for that window.

In another aspect of the present invention, the characteristics of electrical image evaluated by the processor include the width and height of edge segments in the image, as well as, the height, width, and location of objects constructed from multiple edge segments. The position of the window in the electrical image is calculated based on the azimuth angle and the elevation angle of the camera.

In yet another aspect of the present invention, a method is provided for identifying the vehicle within the electrical image and determining the vehicle range. To simplify the image, an edge enhanced algorithm is applied to the image. Only characteristics of the electrical image within a particular window are evaluated. The edge enhanced image is binarized and segmented. The segments are evaluated and objects are constructed from multiple segments. A score is determined for each object based on criteria, such as, the object width, object height position, object height, and segment width. Based on the score of the object, the range of the object is estimated on the basis of the target range of the window.

Further objects, features and advantages of this invention will become readily apparent to persons skilled in the art after a review of the following description, with reference to the drawings and claims that are appended to and form a part of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view of a system for range and lateral position measurement of a preceding vehicle, embodying the principles of the present invention;

FIG. 2 is a view of an electronic image from the perspective of the camera in FIG. 1;

FIG. 3 is a side view of the system illustrating the calculation of the upper and lower edge of the windows in accordance with the present invention;

FIG. 4 is a top view of the system illustrating the calculation of the left and right edge of the windows, in accordance with the present invention;

FIG. 5A is a view of the electronic image, with only the image information in the first window extracted;

FIG. 5B is a view of the electronic image, with only the image information in the second window extracted;

FIG. 5C is a view of the electronic image, with only the image information in the third window extracted;

FIG. 6 is a view of an electronic image generated by the camera prior to processing;

FIG. 7 is a view of the electronic image after a vertical edge enhancement algorithm has been applied to the electronic image;

FIG. 8 is a view of the electronic image including segments that are extracted from the edge enhanced image; and

FIG. 9 is a view of the electronic image including objects constructed from the segments illustrated in FIG. 8.

DETAILED DESCRIPTION

Referring now to FIG. 1, a system embodying the principles of the present invention is illustrated therein and designated at 10. As its primary components, the system 10 includes a camera 12 and a processor 14. The camera 12 is located in the rearview mirror to collect an optical image of a region of interest 16 including a vehicle 18. The optical image received by the camera 12, is converted to an electrical image that is provided to the processor 14. To filter out unwanted distractions in the electronic image and aid in determining the range of the vehicle 18, the processor 14 calculates the position of multiple windows 20, 22, 24 within the region of interest 16. The windows 20, 22, 24 are located at varying target ranges from the camera 12. The size of the windows 20, 22, 24 are a predetermined physical size (about 4×2 m as shown) and may correspond to the size of a typical vehicle. To provide increased resolution the windows 20, 22, 24 are spaced closer together and the number of windows is increased. Although the system 10, as shown, is configured to

track a vehicle **18** preceding the system **10**, it is fully contemplated that the camera **12** could be directed to the side or rear the system **10** to track a vehicle **18** that may be approaching from other directions.

Now referring to FIG. **2**, an electronic image of the region of interest **16** as viewed by the camera **12** is provided. The windows **20, 22, 24** are projected into their corresponding size and location according to the perspective of the camera **12**. The vehicle **18** is located between windows **22** and **24**, accordingly, the size of the vehicle **18** corresponds much more closely to the height and width of windows **22** and **24** than window **20**. As can be seen from FIG. **1**, although the size and width of the windows are physically constant at each target range, the window sizes appear to vary from the perspective of the camera **12**. Similarly, the height and width of the preceding vehicle **18** will appear to vary at each target range. The perspective of the camera **12** will affect the apparent size and location of the preceding vehicle **18** within the electrical image based on the elevation angle and the azimuth angle of the camera **12**. The processor **14** can use the location and size of each of the windows **20, 22, 24** to evaluate characteristics of the electrical image and determine a score indicating the probability the vehicle **18** is at the target range associated with a particular window.

Now referring to FIG. **3**, a side view of the system **10** is provided illustrating the use of the elevation angle in calculating the height and position of the window **20** within the electrical image. The elevation angle is the angle between the optical axis of the camera **12** and the surface of the road. The lower edge of window **20** is calculated based on Equation (1).

$$\Theta_1 = a \tan(-hc/r1) \tag{1}$$

Where hc is the height of the camera **12** from the road surface, r1 is the horizontal range of window **20** from the camera **12**, and the module is $[0, 2\pi]$.

Similarly, the upper edge of the first window is calculated based on Equation (2).

$$\Theta_{1h} = a \tan((hw-hc)/r1) \tag{2}$$

Where hw is the height of the window, hc is the height of the camera **12** from the road surface, r1 is the range of window **20** from the camera **12**, and the module is $[0, 2\pi]$. The difference, $\Delta\Theta_1 = \Theta_1 - \Theta_{1h}$, corresponds to the height of the window in the electronic image.

Now referring to FIG. **4**, the horizontal position of the window in a picture corresponds to the azimuth angle. The azimuth angle is the angle across the width of the preceding vehicle from the perspective of the camera **12**. The right edge of the range window **20** is calculated according to Equation (3).

$$\Phi_1 = a \tan(-width\_w/r1) + (\pi/2) \tag{3}$$

Similarly, the left edge of the range window **20** is calculated according to Equation (4).

$$\Phi_{1h} = a \tan(width\_w/r1) + (\pi/2) \tag{4}$$

Where window w is the distance from the center of the window **20** to the horizontal edges, r1 is the horizontal range of the window **20** from the camera **12**, and the module is $[0, 2\pi]$. The window positions for the additional windows **22, 24** are calculated according to Equations (1)-(4), substituting their respective target ranges for r1.

Now referring to FIG. **5A**, the electronic image is shown relative to window **20**. Notice the width of the object **26** is about 30% of the width of the window **20**. If the window width is set at a width of 4 m, about twice the expected width

of the vehicle **18**, the estimated width of the object **26** at a distance of r1 would equal 4×0.3=1.2 m. Therefore, the likelihood that the object **26** is the vehicle **18** at range r1 is low. In addition, the processor **14** evaluates vertical offset and object height criteria. For example, the distance of the object **26** from the bottom of the processing window **20** is used in determining likelihood that the object **26** is at the target range. Assuming a flat road, if the object **26** were at the range r1, the lowest feature of the object **26** would appear at the bottom of the window **20** corresponding to being in contact with the road at the target range. However, the object **26** in FIG. **5A**, appears to float above the road, thereby decreasing the likelihood it is located at the target range. Further, the extracted object **26** should have a height of 0.5 m or 1.2 m. The processor **14** will detect an object height of 0.5 m if only the bottom portion of the vehicle **18** is detected or 1.2 m if the full height of the vehicle **18** is detected. The closer the height of the object **26** is to the expected height the more probable the object **26** is the vehicle **18** and the more probable it is located at the target range r1. The vertical offset, described above, may also affect the height of the object **26**, as the top of the object, in FIG. **5A**, is chopped off by the edge of the window **20**. Therefore, the object **26** appears shorter than expected, again lowering the likelihood the object is the vehicle **18** at the range r1.

Now referring to FIG. **5B**, the electronic image is shown relative to window **22**. The width of the object **27** is about 45% of the window **22**. Therefore, the estimated width of the object **27** at range r2 is equal to 4×0.45−1.8 m much closer to the expected size of the vehicle **18**. In this image, the object **27** is only slightly offset from the bottom of the window **22**, and the entire height of the object **27** is still included in the window **22**.

Now referring to FIG. **5C**, the electronic image is shown relative to window **24**. The width of the object **28** is about 80% of the width of the window **24**. Accordingly, the estimated width of the object **28** at range r3 is equal to 4×0.08=3.2 m. Therefore, the object width is significantly larger than the expected width of vehicle **18**, usually about 1.75 m. Based on the object width, the processor **14** can make a determination that object **27** most probably corresponds to vehicle **18** and r2 is the most probable range. The range accuracy of the system **10** can be increased by using a finer pitch of target range for each window. Using a finer pitch between windows is especially useful as the vehicle **18** is closer to the camera **12**, due to the increased risk of collision. Alternatively, interpolation may also be used to calculate a position between windows by identifying two most probable objects in successive windows, using the above mentioned criteria, and calculating a distance base on a weighting of each score and the corresponding target ranges.

Now referring to FIG. **6**, a typical electronic image as seen by the camera **12** is provided and will be used to further describe the method implemented by the processor **14** to determine the range and lateral position of the vehicle **18**. The electronic image includes additional features that could be confusing for the processor **14** such as the lane markings **30**, an additional car **32**, and a motorcycle **34**.

FIG. **7** shows a vertically edge enhanced image. The electronic image is comprised of horizontal rows and vertical columns of picture elements (pixels). Each pixel contains a value corresponding to the brightness of the image at that row and column location. A typical edge enhancement algorithm includes calculating the derivative of the brightness across the horizontal rows or vertical columns of the image. However, many other edge enhancement techniques are contemplated and may be readily used. In addition, the position and size of

the window **36** is calculated for a given target range. Edge information located outside the window **36** is ignored. In this instance, much of the edge enhanced information from the car **38** and the motorcycle **40** can be eliminated.

Now referring to FIG. **8**, the edge enhanced image is then binarized, meaning each of the pixels are set to a 1 or 0 value. A typical method for binarizing the image includes taking the absolute value of each pixel value and applying a threshold value, where if the brightness of the pixel value is above the threshold value, the pixel value is set to 1. Otherwise, the pixel value is set to 0. Although, the above described method is fast and simple, other more complicated thresholding methods may be used including local area thresholding or other commonly used approaches. Next, the pixels are grouped based on their relative position to other pixels having the same value. Grouping of these pixels is called segmentation and each of the groups is referred to as a segment. Height, width and position information is stored for each segment.

Relating these segments back to the original image, Segment **42** represents the lane marking on the road. Segment **44** represents the upper portion of the left side of the vehicle. Segment **46** represents the lower left side of the vehicle. Segment **48** represents the left tire of the vehicle. Segment **50** represents the upper right side of the vehicle. Segment **52** represents the lower right side of the vehicle while segment **54** represents the right tire.

Now referring to FIG. **9**, objects may be constructed from two segments. Segment **42** and segment **44** are combined to construct object **56**. Segment **42** and segment **46** are combined to construct object **58**. In segment **46** and segment **52** are combined to construct object **60**. Each of the objects are then scored based on the width of the object, the height of the object, the position of the object relative to the bottom edge of the window, the segment width, and the segment height. The above process is repeated for multiple windows with different target ranges. The object with the best score is compared with a minimum score threshold. If the best score is higher than the minimum score threshold the characteristics of the object are used to determine the object's range and lateral position.

As a person skilled in the art will readily appreciate, the above description is meant as an illustration of implementation of the principles this invention. This description is not intended to limit the scope or application of this invention in that the invention is susceptible to modification, variation and change, without departing from spirit of this invention, as defined in the following claims.

I claim:

1. A system for determining range of a vehicle, the system comprising:
   a camera configured to view a region of interest including the vehicle and generate an electrical image of the region;
   a processor in electrical communication with the camera to receive the electrical image, wherein the processor is configured to identify a plurality of windows within the electrical image, each window of the plurality of windows corresponding to a predetermined physical size at a target range from the camera, the processor being further configured to evaluate characteristics of the electrical image in relation to each window to identify the vehicle;
   wherein the processor is configured to determine a score indicating likelihood the vehicle is at the target range; and
   wherein the processor is configured to determine the score based on a size ratio between each window and the characteristics of the electrical image.

2. The system according to claim **1**, wherein the predetermined physical size is based on vehicle characteristics.

3. The system according to claim **2**, wherein the vehicle characteristics include a width of the vehicle.

4. The system according to claim **2**, wherein the vehicle characteristics include a height of the vehicle.

5. The system according to claim **1**, wherein the characteristics of the electrical image include edge segments within the electrical image.

6. The system according to claim **5**, wherein the edge segments are vertical edge segments.

7. The system according to claim **5**, wherein the characteristics of the electrical image include a height of the edge segments.

8. The system according to claim **5**, wherein the characteristics of the electrical image include a width of the edge segments.

9. The system according to claim **5**, wherein the characteristics of the electrical image include objects constructed from the edge segments.

10. The system according to claim **9**, wherein the characteristics of the electrical image include a height of the objects.

11. The system according to claim **9**, wherein the characteristics of the electrical image include a width of the objects.

12. The system according to claim **1**, wherein a position of each window is determined based on the target range.

13. The system according to claim **1**, wherein the window position is determined based on an elevation angle of the camera.

14. The system according to claim **13**, wherein the lower edge of each window is calculated based on the relationship $\Theta_1 = \mathrm{atan}(-hc/r1)$ where hc is the height of the camera from the road surface, r1 is the range of window from the camera, and the module is $[0, 2\pi]$.

15. The system according to claim **13**, wherein the upper edge of each window is calculated based on the relationship $\Theta_{1h} = \mathrm{atan}((hw-hc)/r1)$ where hw is a window height, hc is the height of the camera from the road surface, r1 is the range of window from the camera, and the module is $[0, 2\pi]$.

16. The system according to claim **1**, wherein the position of each window is determined based on an azimuth angle of the camera.

17. The system according to claim **16**, wherein the right edge of each window is calculated based on the relationship $\Theta_1 = \mathrm{atan}(-width\_w/r1) + \pi/2$ where window w is the distance from the center of the window to the horizontal edges, r1 is the horizontal range of the window from the camera, and the module is $[0, 2\pi]$.

18. The system according to claim **16**, wherein the left edge of each window is calculated based on the relationship $\phi_{1h} = \mathrm{atan}(width\_w/r1) + \pi/2$ where window w is the distance from the center of the window to the horizontal edges, r1 is the horizontal range of the window from the camera, and the module is $[0, 2\pi]$.

19. A method for determining range of a vehicle the method comprising:
   using one or more processor to receive an optical image of a region of interest onto a camera; generating an electrical image based on the optical image; identifying a plurality of windows within the electrical image, each window corresponding to a predetermined physical size at a target range from the camera; and
   evaluating characteristics of the electrical image within each window to identify the vehicle;
   determining a score indicating likelihood the vehicle is at the target range based on a size ratio between each window and the characteristics of the electrical image.

20. The method according to claim **19**, wherein the predetermined physical size is based on vehicle characteristics.

21. The method according to claim **20**, wherein the vehicle characteristics include a width of the vehicle.

22. The method according to claim **20**, wherein the vehicle characteristics include a height of the vehicle.

23. The method according to claim **19**, wherein the characteristics of the electrical image include edge segments within the electrical image.

24. The method according to claim **23**, wherein the edge segments are vertical edge segments.

25. The method according to claim **23**, wherein the characteristics of the electrical image include a height of the edge segments.

26. The method according to claim **23**, wherein the characteristics of the electrical image include a width of the edge segments.

27. The method according to claim **23**, wherein the characteristics of the electrical image include objects constructed from the edge segments.

28. The method according to claim **27**, wherein the characteristics of the electrical image include a height of the objects.

29. The method according to claim **27**, wherein the characteristics of the electrical image include a width of the objects.

30. The method according to claim **19**, wherein a position of each window is determined based on the target range.

31. The method according to claim **19**, wherein the window position is determined based on an elevation angle of the camera.

32. The method according to claim **31** wherein the lower edge of each window is calculated based on the relationship $\Theta_1 = \text{atan}(-hc/r1)$ where hc is the height of the camera from the road surface, r1 is the range of window from the camera, and the module is $[0, 2\pi]$.

33. The method according to claim **31**, wherein the upper edge of each window is calculated based on the relationship $\Theta_{1h} = \text{atan}((hw-hc)/r1)$ where hw is a window height, hc is the height of the camera from the road surface, r1 is the range of window from the camera, and the module is $[0, 2\pi]$.

34. The method according to claim **19**, wherein the position of each window is determined based on an azimuth angle of the camera.

35. The method according to claim **34**, wherein the right edge of each window is calculated based on the relationship $\Phi_1 = \text{atan}(-\text{width\_w}/r1) + \pi/2$ where window w is the distance from the center of the window to the horizontal edges, r1 is the horizontal range of the window from the camera, and the module is $[0, 2\pi]$.

36. The method according to claim **34**, wherein the left edge of each window is calculated based on the relationship $\Phi_{1h} = \text{atan}(\text{width\_w}/r1) + \pi/2$ where window w is the distance from the center of the window to the horizontal edges, r1 is the horizontal range of the window from the camera, and the module is $[0, 2\pi]$.

37. The method according to claim **19**, wherein evaluating characteristics of the electrical image includes performing an edge enhancement algorithm to the electrical image.

38. The method according to claim **37**, wherein the edge enhancement algorithm is a vertical edge enhancement algorithm.

39. The method according to claim **37**, wherein evaluating characteristics of the electrical image includes extracting only the electrical image within the window.

40. The method according to claim **37**, wherein evaluating characteristics of the electrical image includes binarizing the electrical image utilizing a threshold.

41. The method according to claim **37**, wherein evaluating characteristics of the electrical image includes identifying segments from the binarized image.

42. The method according to claim **41**, wherein evaluating characteristics of the electrical image includes constructing objects from the segments.

43. The method according to claim **42**, wherein evaluating the electrical image, includes determining a score for each object based on the object width, object height position, object height, and segment width.

44. The method according to claim **43**, wherein evaluating characteristics of the electrical image, further includes determining a range of the object that is based on the score of the object.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO.   : 7,561,720 B2   Page 1 of 1
APPLICATION NO. : 10/836501
DATED   : July 14, 2009
INVENTOR(S)   : Shunji Miyahara

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

On the Title Page

       Item (75), replace "Yokohama" with --Yokohama-shi--.

Page 2

       Right column, under "OTHER PUBLICATIONS", insert the following:
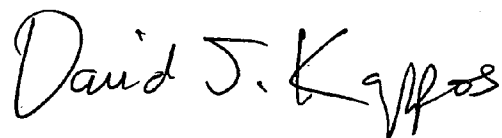
       --Dagan et al., Forward Collision Warning with a Single Camera, IEEE
       Intelligent Vehicles Symposium 14-17, June 2004, pages 37-42--.

In the Claims

       In column 6, claim 17, line 45, before "=atan" replace "θ_1" with --ϕ_1--.

Signed and Sealed this

Ninth Day of March, 2010

David J. Kappos
Director of the United States Patent and Trademark Office