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(54) VISION-BASED OBJECT SENSING AND HIGHLIGHTING IN VEHICLE IMAGE DISPLAY SYSTEMS

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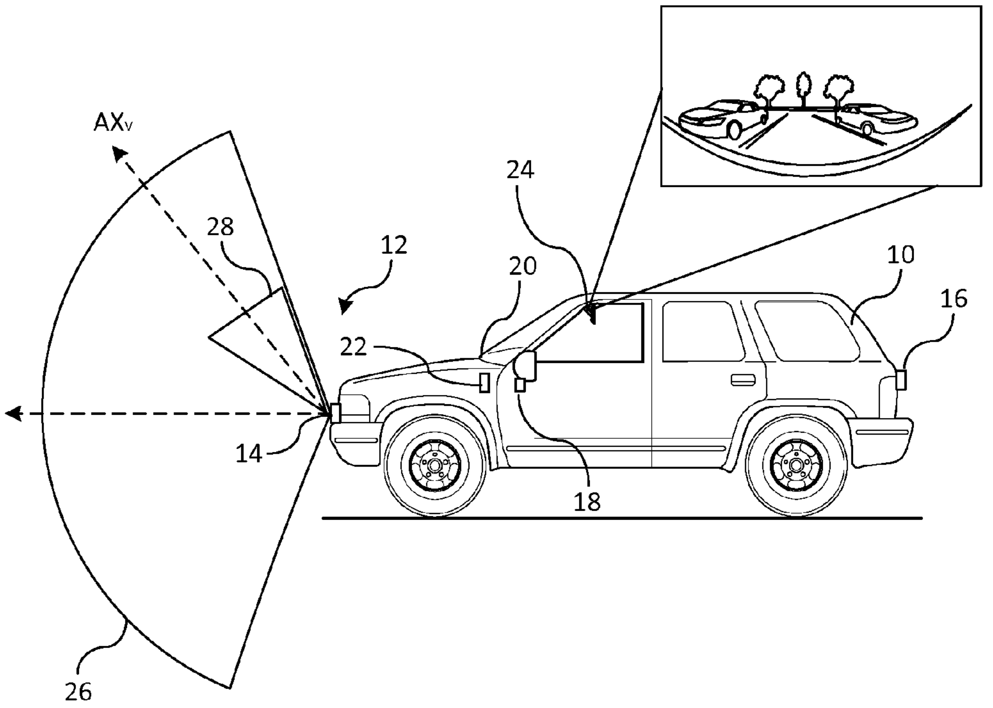
(57) ABSTRACT

A method of displaying a captured image on a display device of a driven vehicle. A scene exterior of the driven vehicle is captured by an at least one vision-based imaging and at least one sensing device. A time-to-collision is determined for each object detected. A comprehensive time-to-collision is determined for each object as a function of each of the determined time-to-collisions for each object. An image of the captured scene is generated by a processor. The image is dynamically expanded to include sensed objects in the image. Sensed objects are highlighted in the dynamically expanded image. The highlighted objects identifies objects proximate to the driven vehicle that are potential collisions to the driven vehicle. The dynamically expanded image with highlighted objects and associated collective time-to-collisions are displayed for each highlighted object in the display device that is determined as a potential collision.



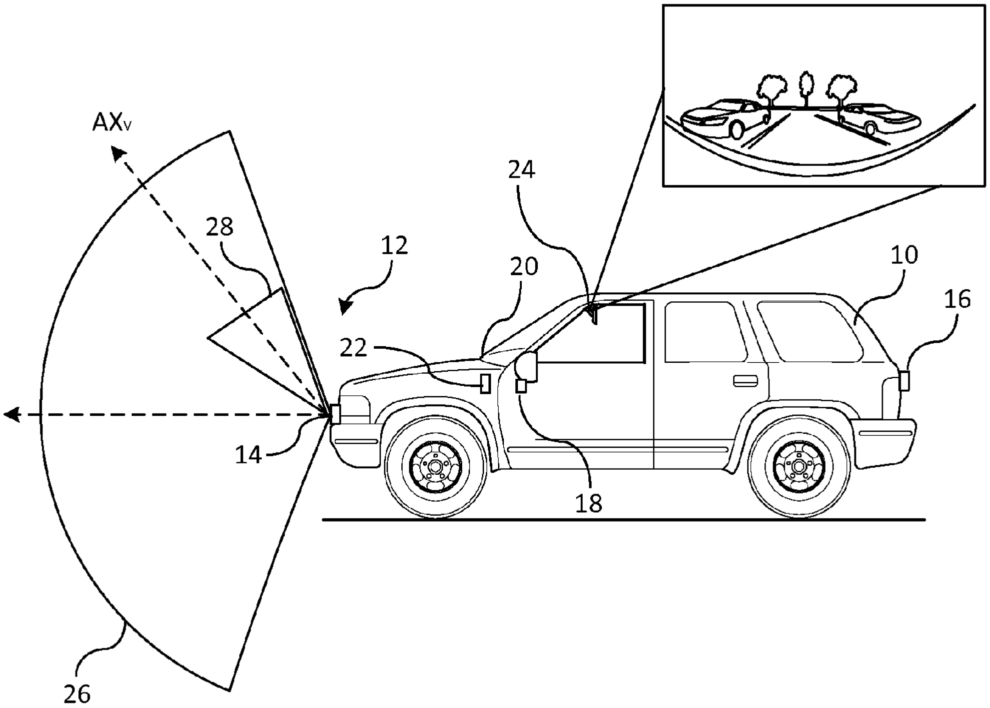


Fig. 1

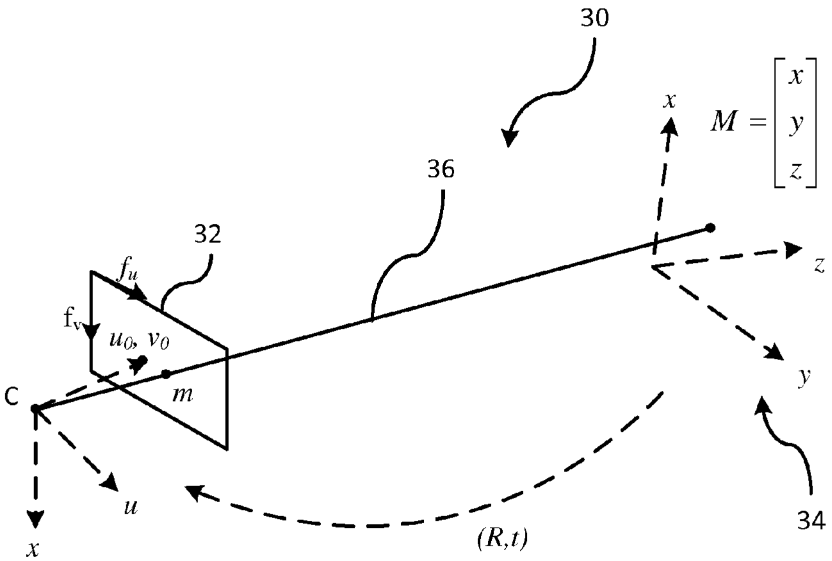

30
x
$M = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$
36
32
f_u
f_v
u_0, v_0
C
m
z
y
u
x
(R,t)
34

Fig. 2

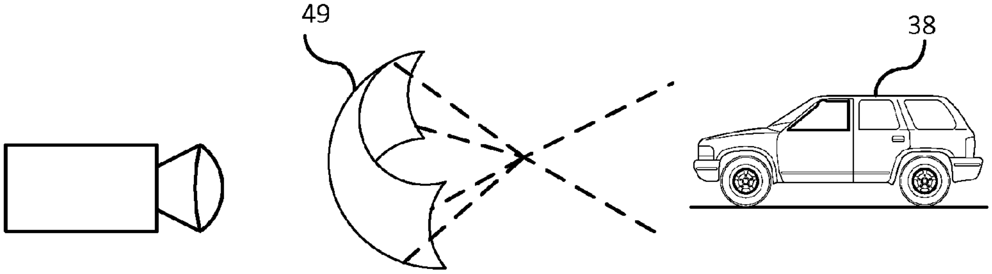

49
38

Fig. 3

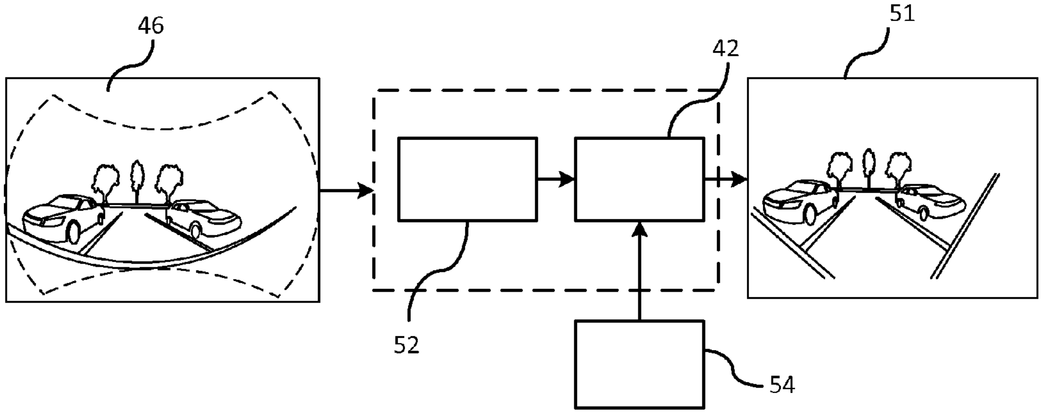


Fig. 4

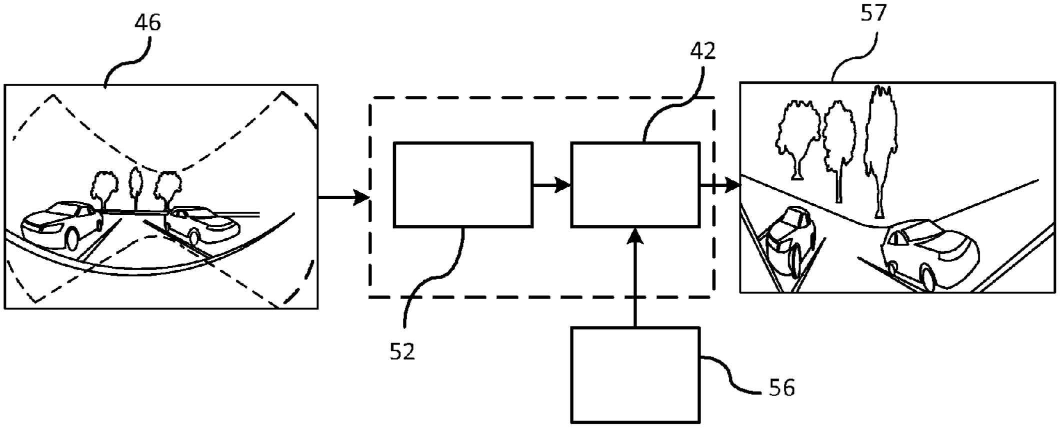


Fig. 5

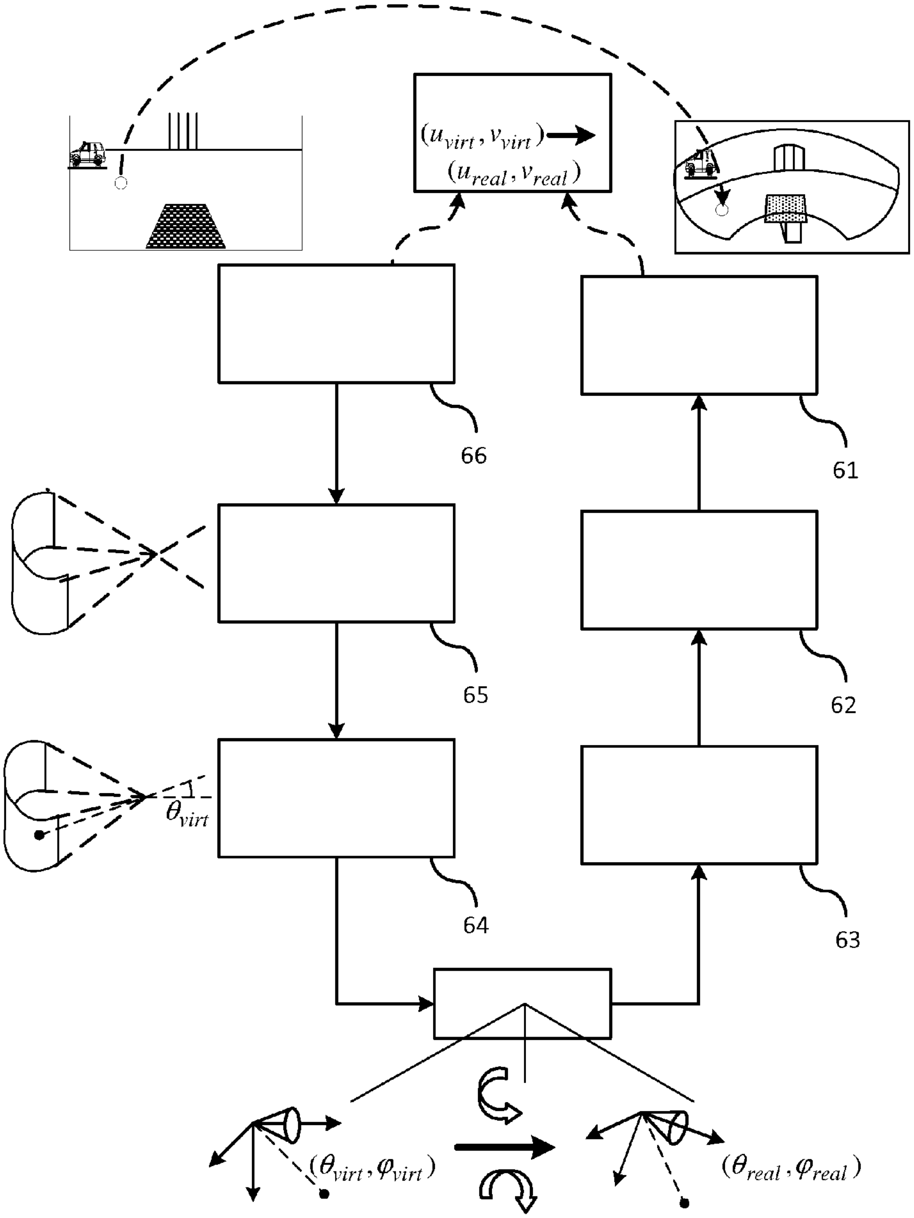

$(u_{virt}, v_{virt}) \rightarrow (u_{real}, v_{real})$
66
61
65
62
θ_{virt}
64
63
$(\theta_{virt}, \varphi_{virt})$
$(\theta_{real}, \varphi_{real})$

Fig. 6

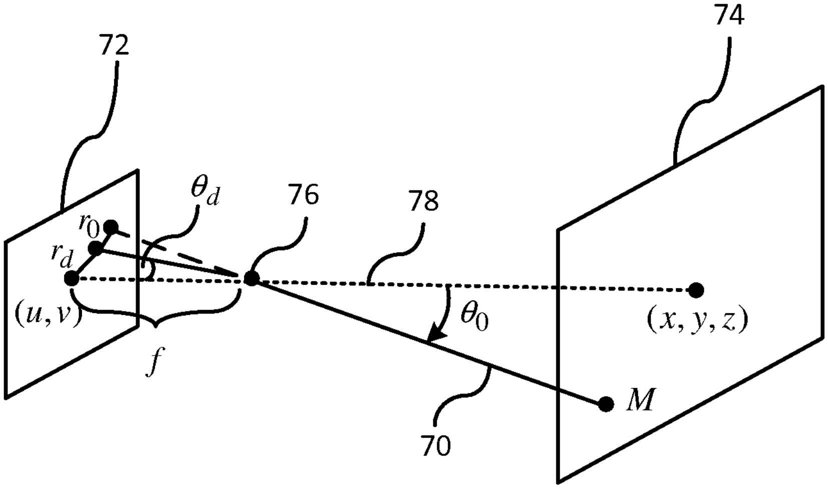

72
74
θ_d
76
78
r_0
r_d
(u, v)
f
θ_0
(x, y, z)
M
70

Fig. 7

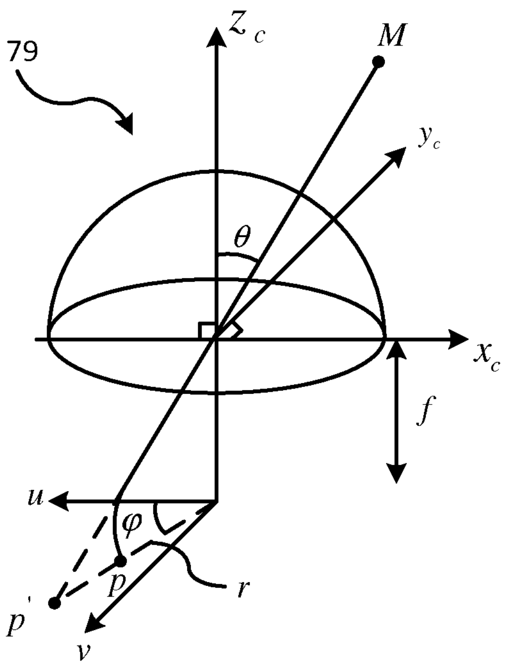

z_c
79
M
y_c
θ
x_c
f
u
φ
p
r
p'
v

Fig. 8

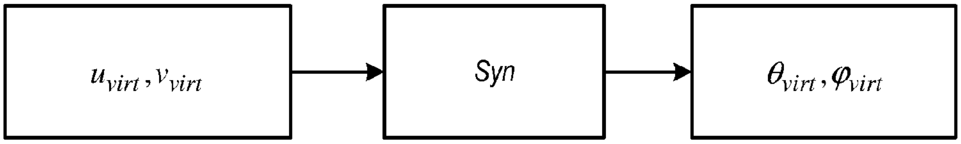


Fig. 9

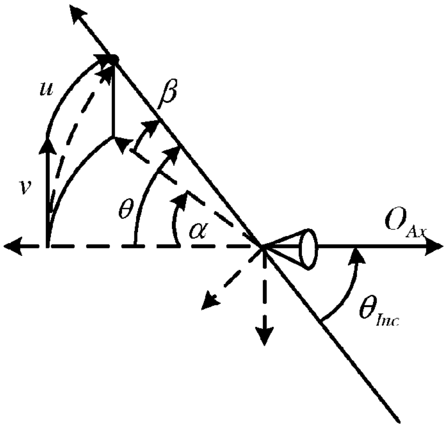
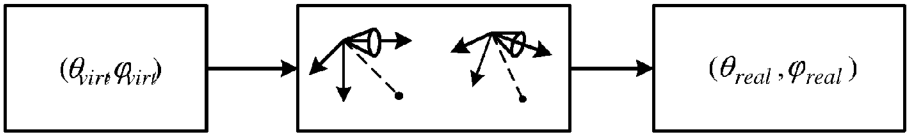


Fig. 10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$(\theta_{real}, \varphi_{real})$

Fig. 11

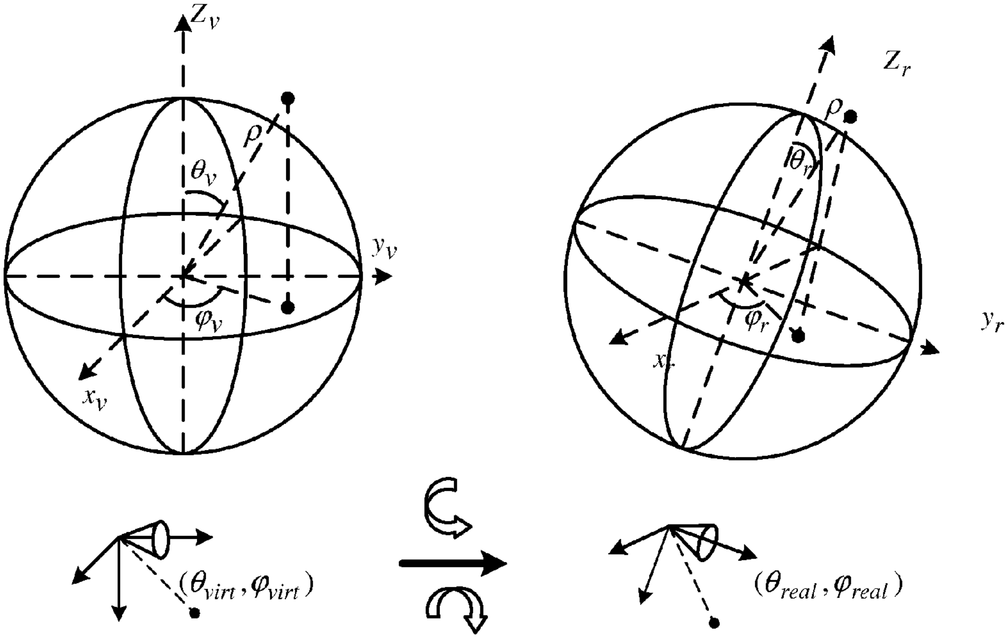
Z_v
ρ
θ_v
y_v
φ_v
x_v
Z_r
ρ
θ_r
φ_r
y_r
x_r
$(\theta_{virt}, \varphi_{virt})$
$(\theta_{real}, \varphi_{real})$

Fig. 12

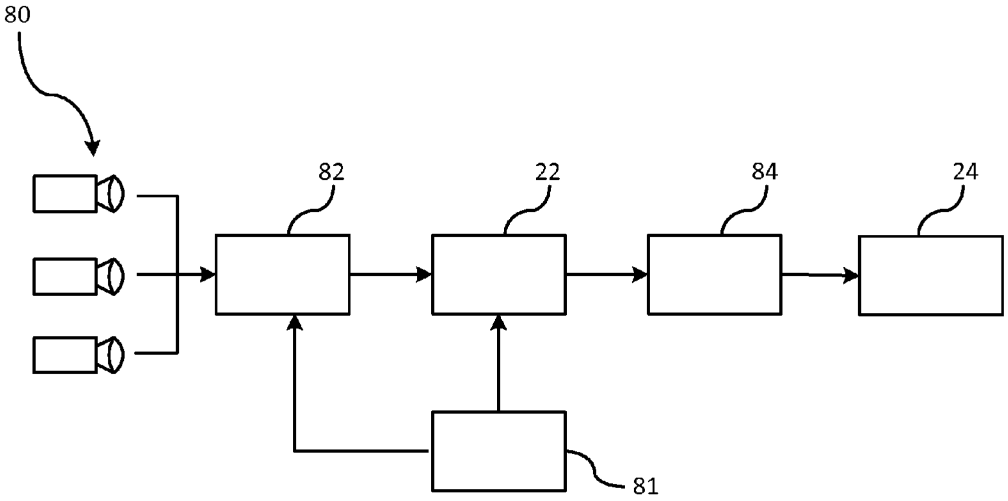

Fig. 13

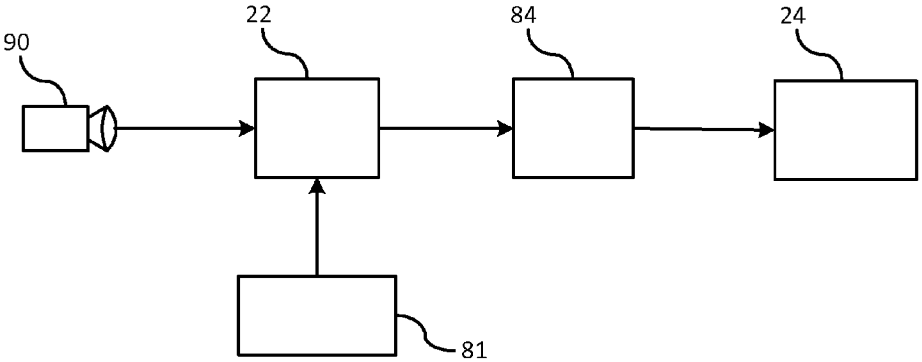

Fig. 14

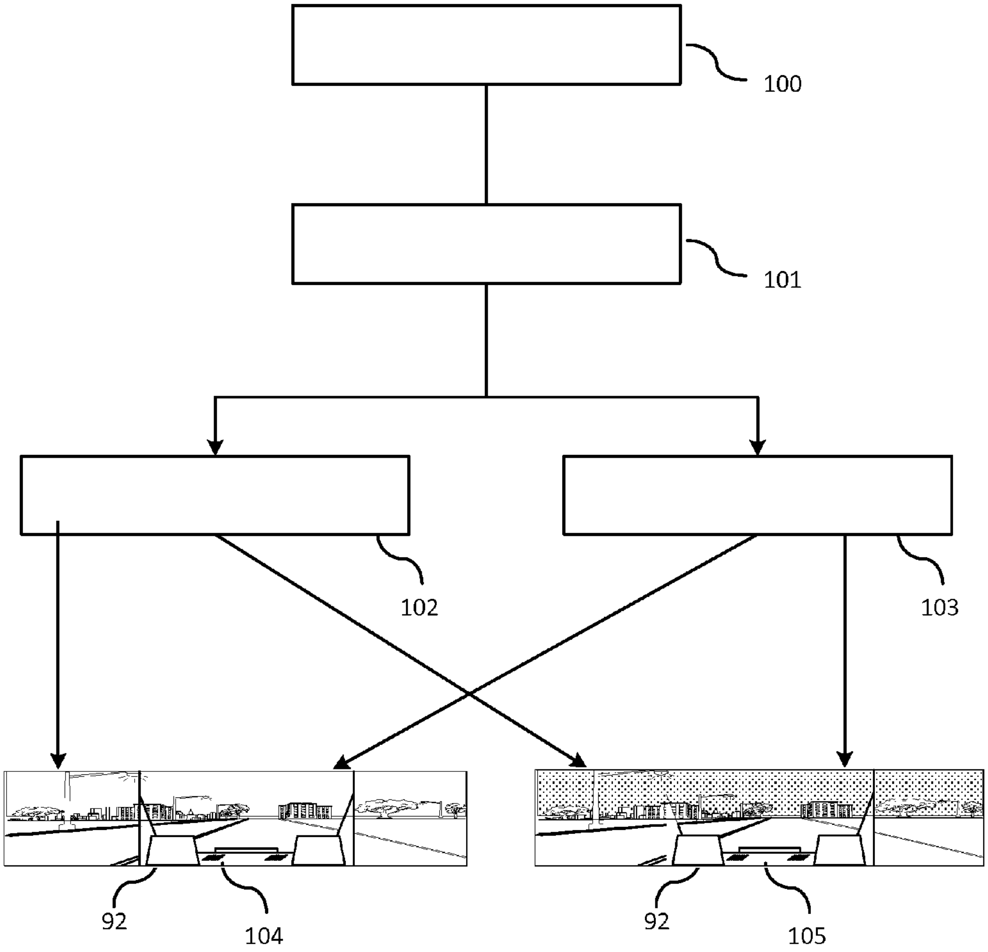

Fig. 15

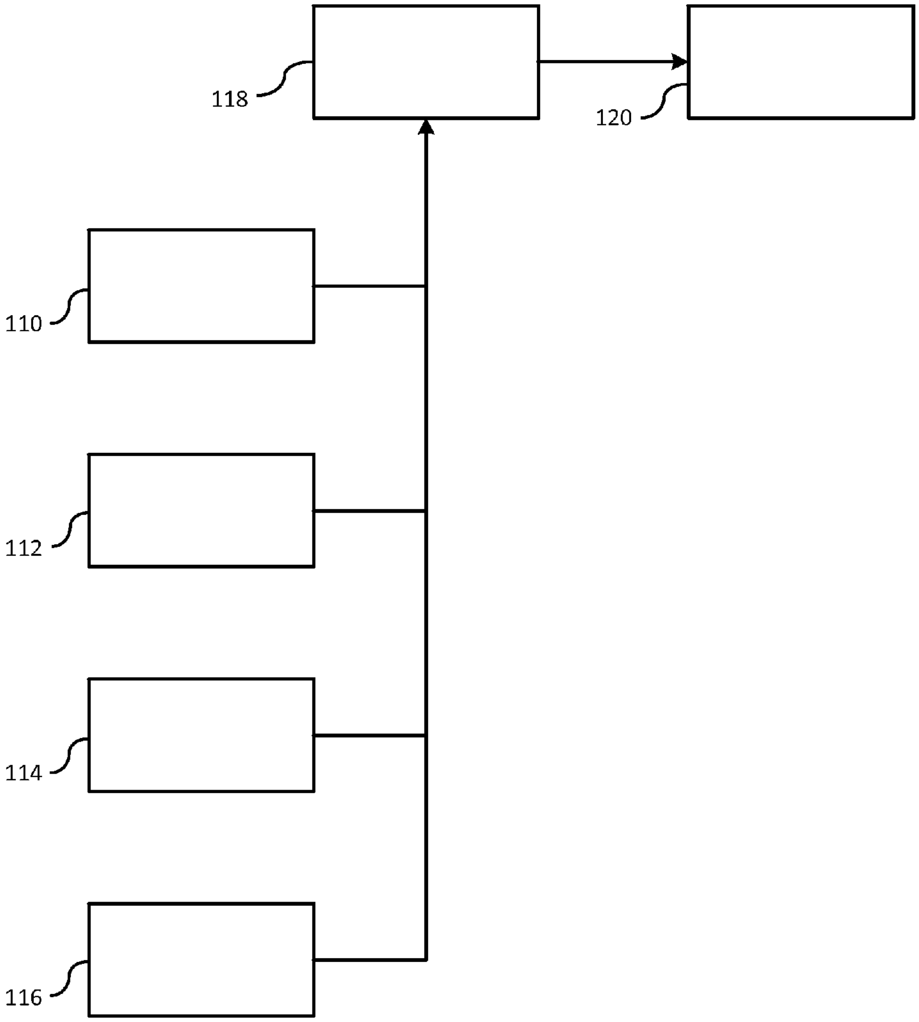

Fig. 16

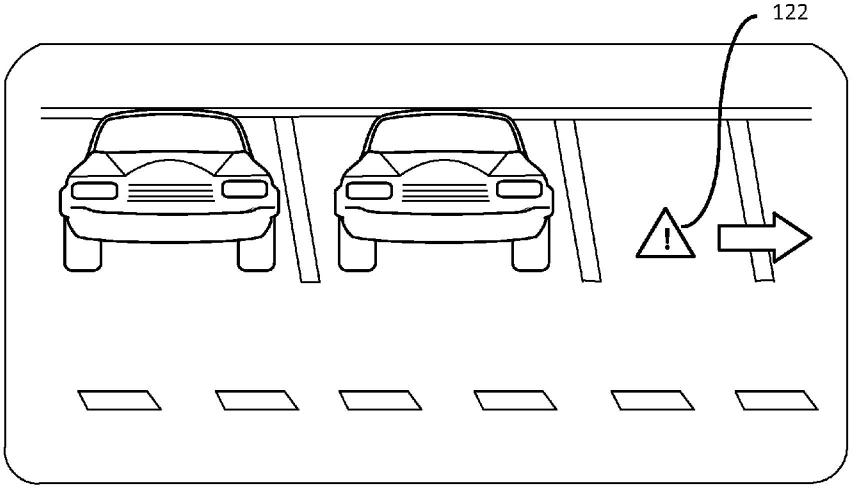

Fig. 17

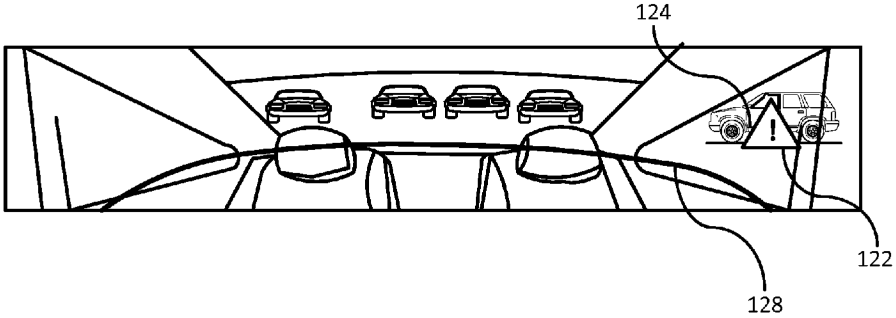

Fig. 18

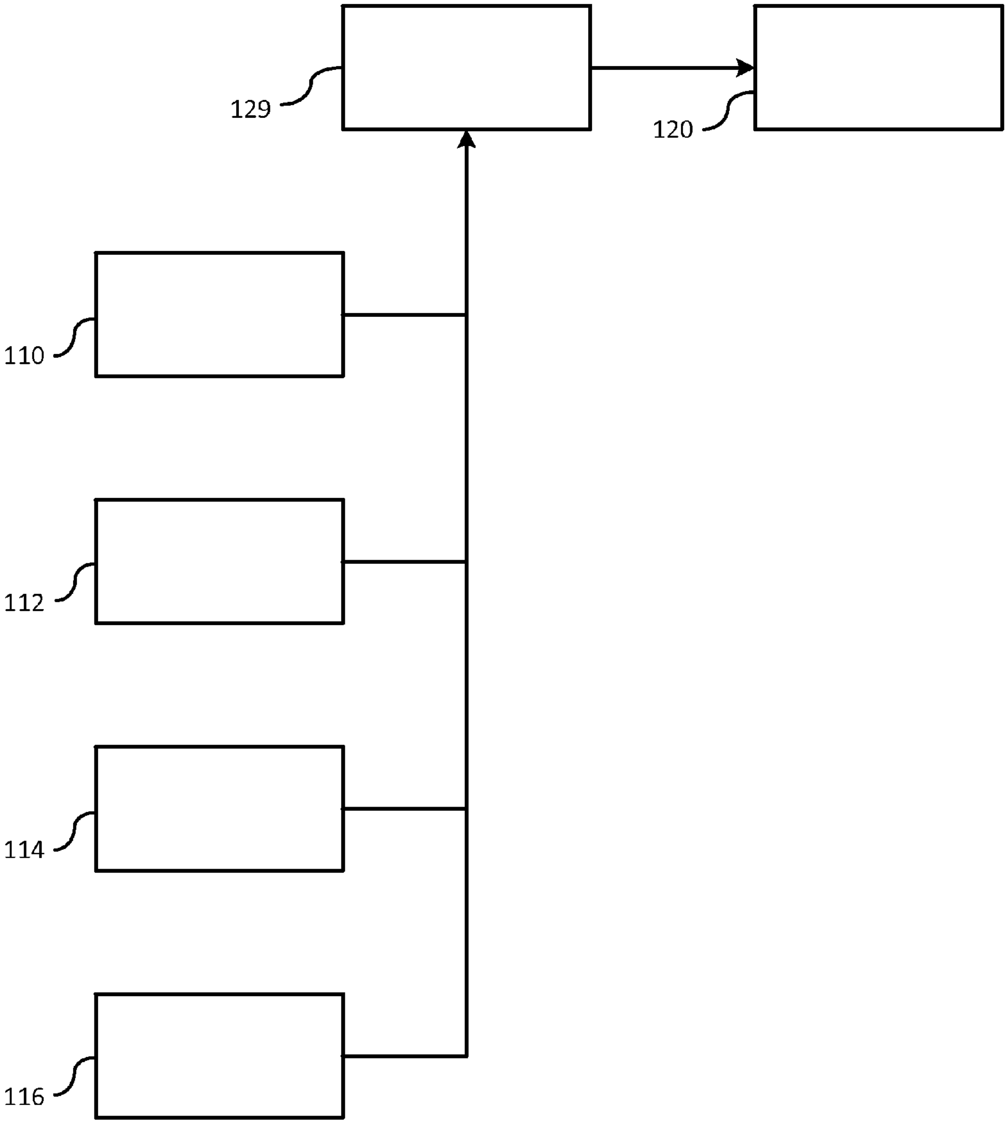

Fig. 19

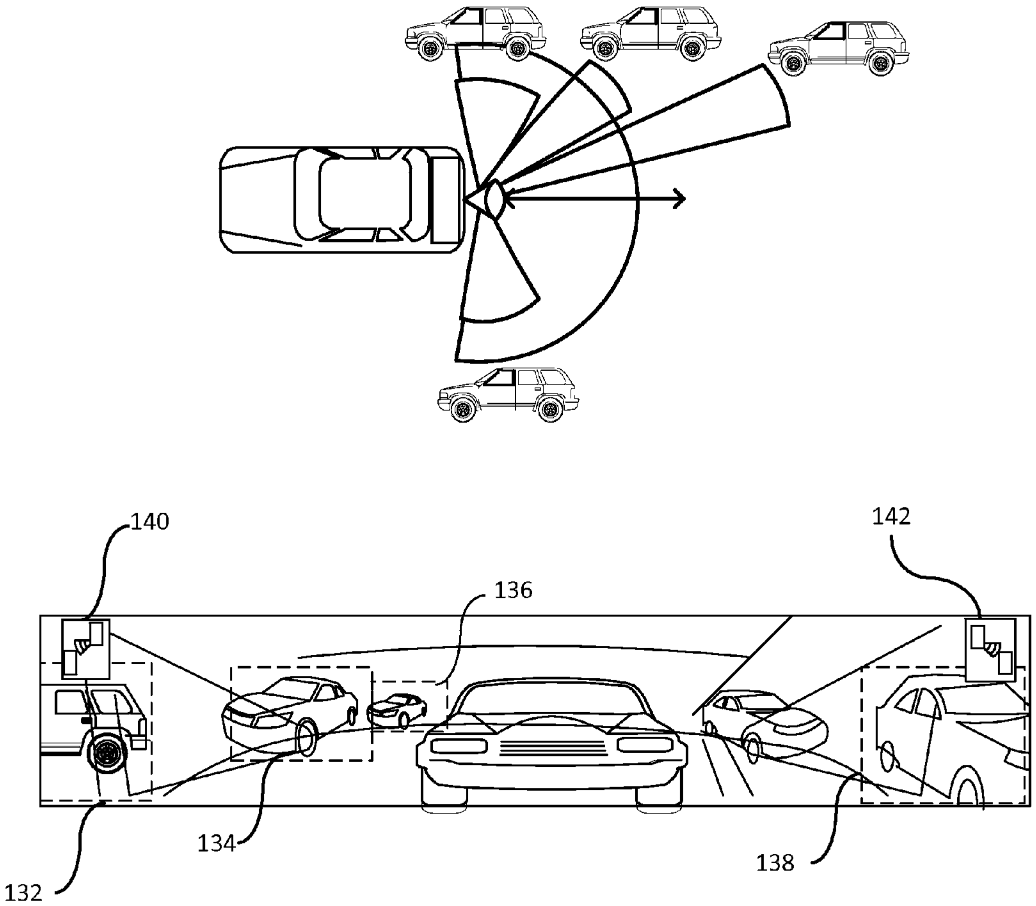

Fig. 20

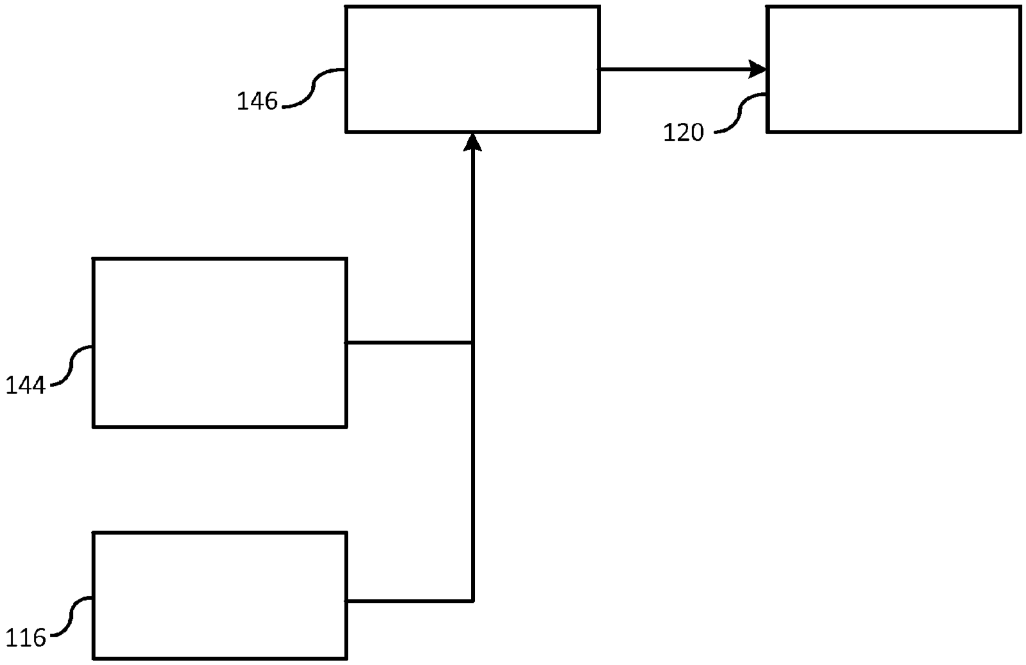

Fig. 21

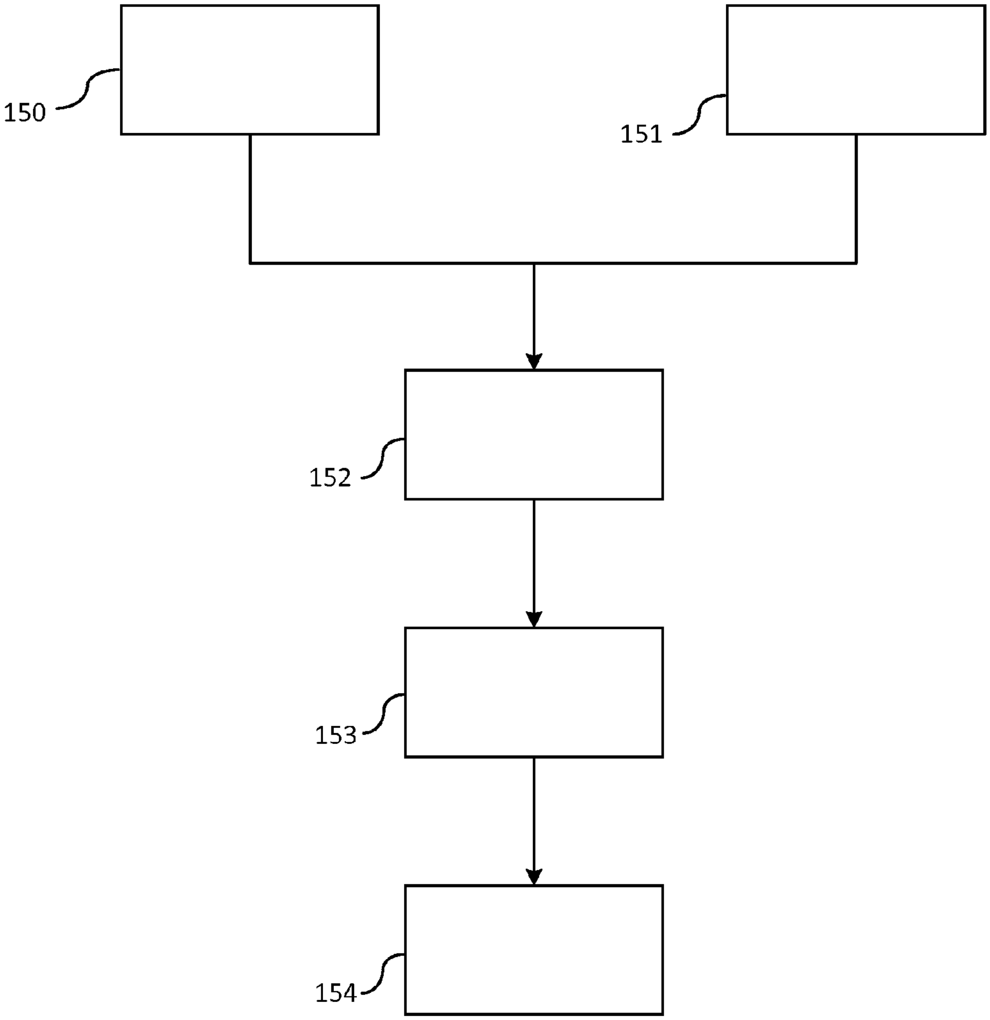

Fig. 22

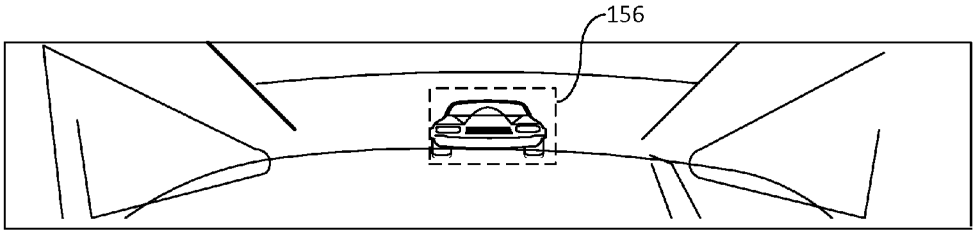

Fig. 23

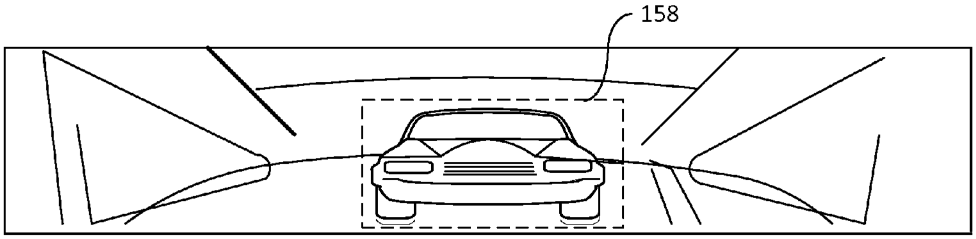

Fig. 24

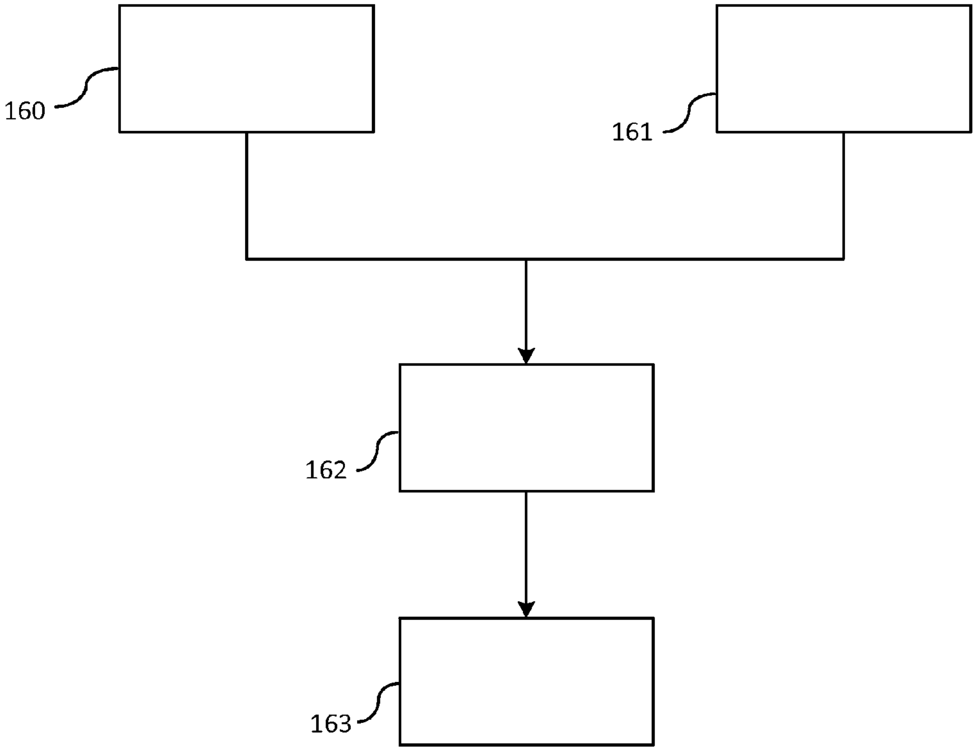

Fig. 25

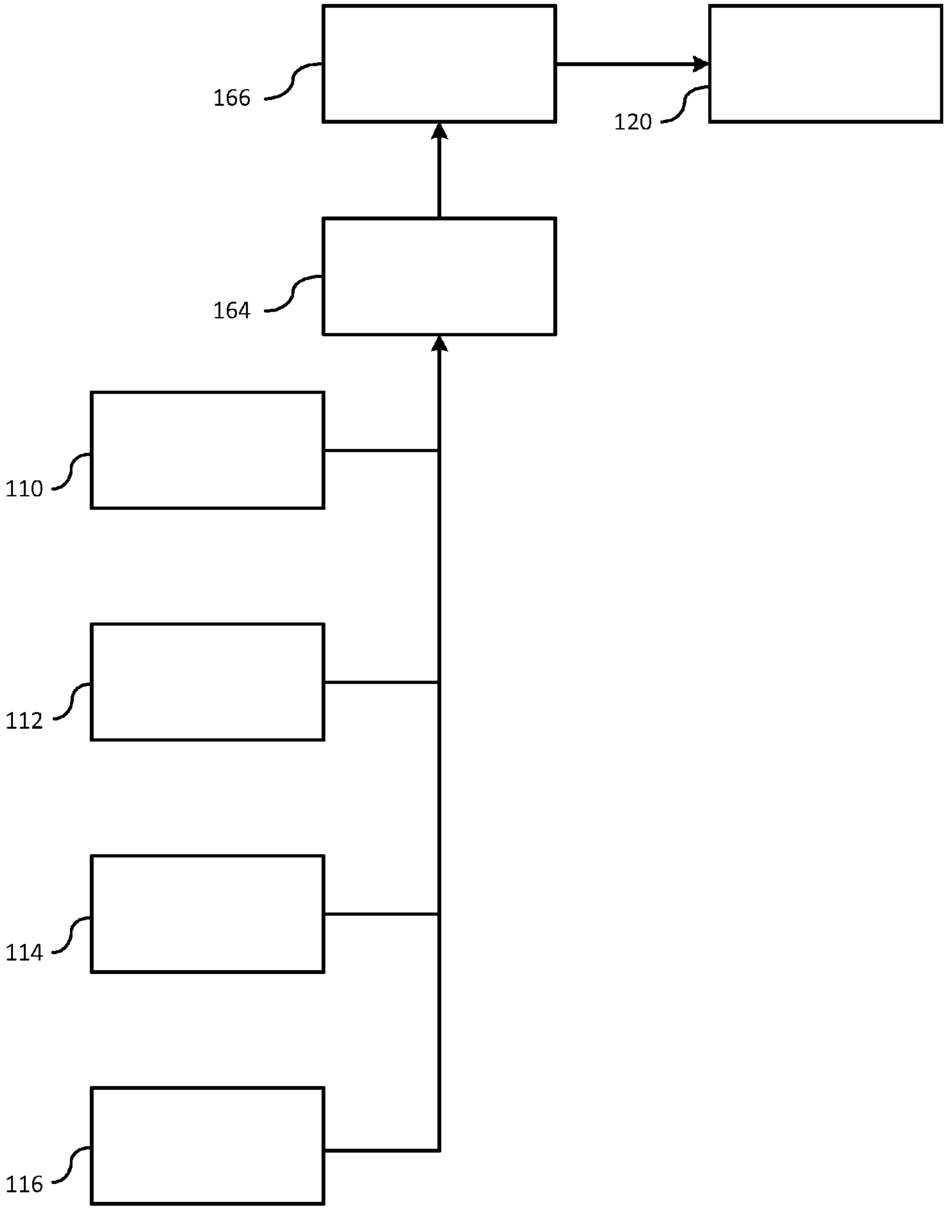

Fig. 26

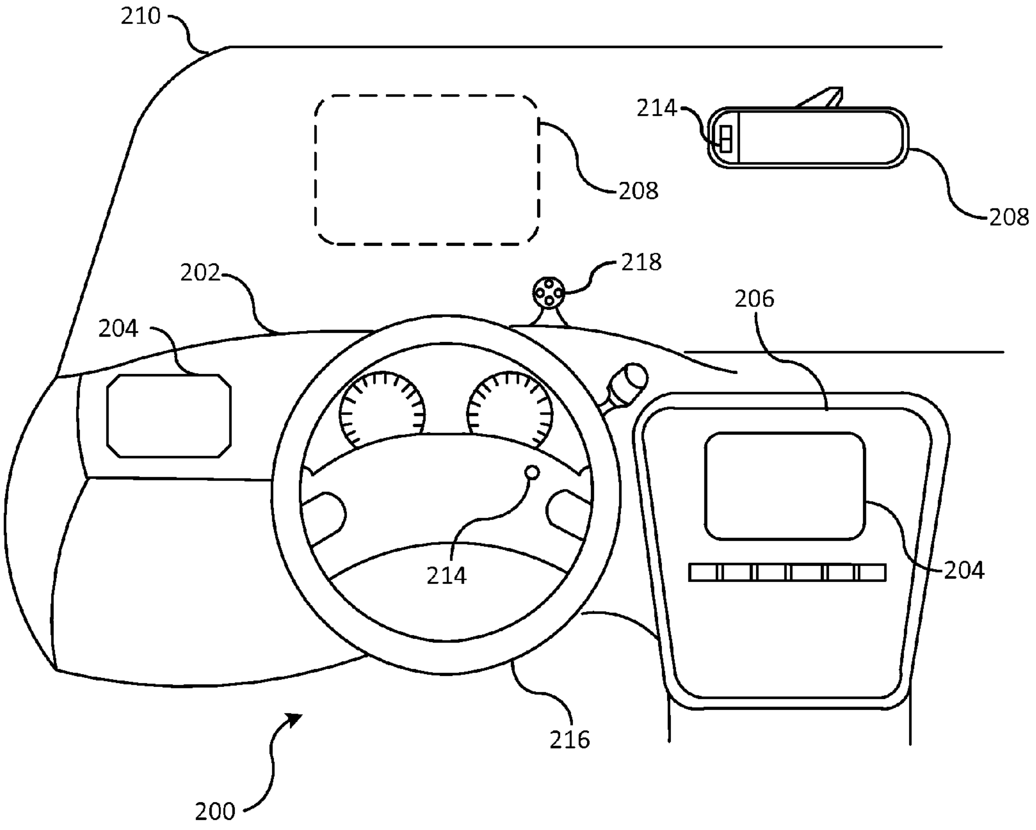

Fig. 27

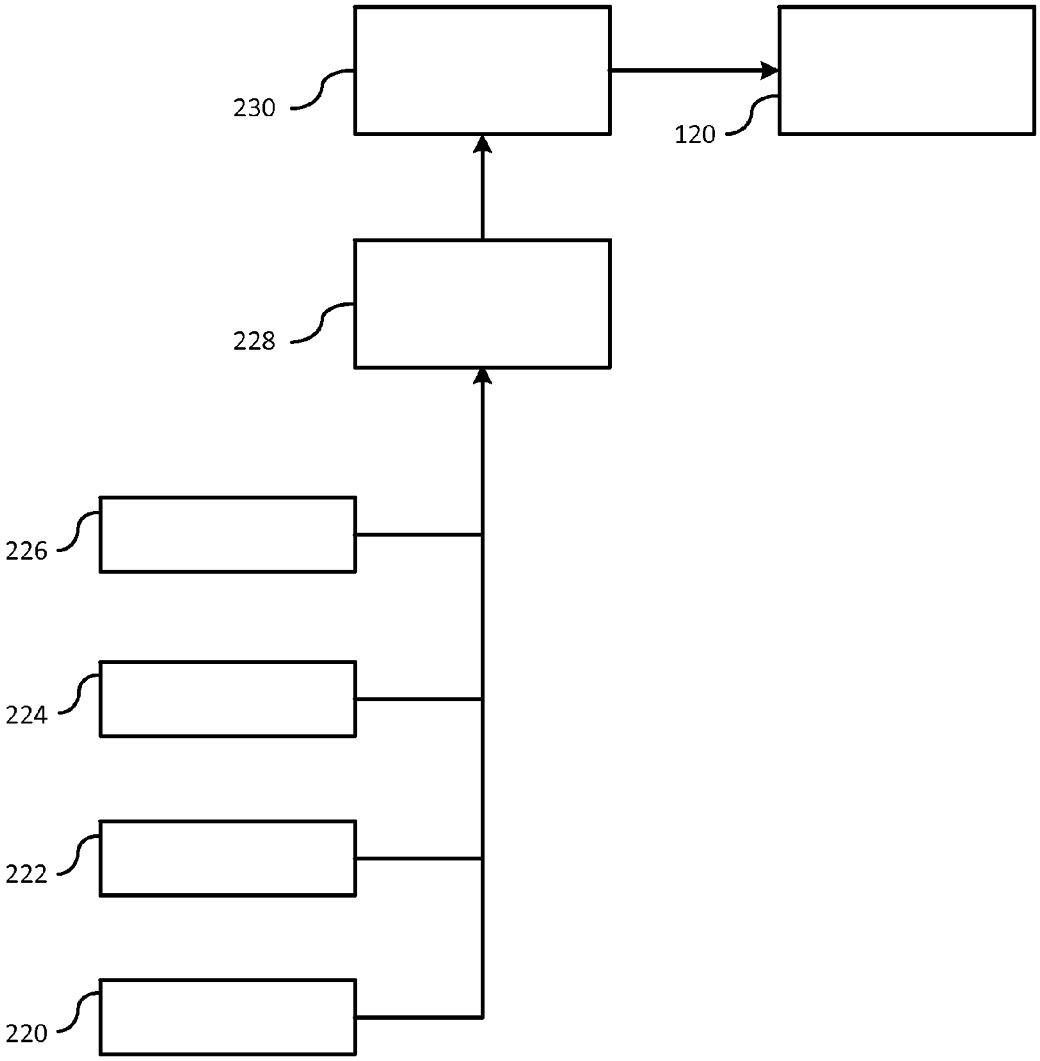

Fig. 28

VISION-BASED OBJECT SENSING AND HIGHLIGHTING IN VEHICLE IMAGE DISPLAY SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The application is a continuation-in-part of U.S. application Ser. No. 14/059,729, filed Oct. 22, 2013.

BACKGROUND OF INVENTION

[0002] An embodiment relates generally to image capture and display in vehicle imaging systems.

[0003] Vehicle systems often use in-vehicle vision systems for rear-view scene detection. Many cameras may utilize a fisheye camera or similar that distorts the captured image displayed to the driver such as a rear back up camera. In such instance when the view is reproduced on the display screen, due to distortion and other factors associated with the reproduced view, objects such as vehicles approaching to the sides of the vehicle may be distorted as well. As a result, the driver of the vehicle may not take notice that of the object and its proximity to the driven vehicle. As a result, a user may not have awareness of a condition where the vehicle could be a potential collision to the driven vehicle if the vehicle crossing paths were to continue, as in the instance of a backup scenario, or if a lane change is forthcoming. While some vehicle system of the driven vehicle may attempt to ascertain the distance between the driven vehicle and the object, due to the distortions in the captured image, such system may not be able to determine such parameters that are required for alerting the driver of relative distance between the object and a vehicle or when a time-to-collision is possible.

SUMMARY OF INVENTION

[0004] An advantage of an embodiment is the display of vehicles in a dynamic rearview mirror where the objects such as vehicles are captured by a vision based capture device and objects identified are highlighted for generating an awareness to the driver of the vehicle and a time-to-collision is identified for highlighted objects. The time-to-collision is determined utilizing temporal differences that are identified by generating an overlay boundary about changes to the object size and the relative distance between the object and the driven vehicle.

[0005] Detection of objects by sensing devices other than the vision-based capture device are cooperatively used to provide a more accurate location of an object. The data from the other sensing devices are fused with data from the vision based imaging device for providing a more accurate location of the position of the vehicle relative to the driven vehicle.

[0006] In addition to cooperatively utilizing each of the sensing devices and image capture device to determine a more precise location of the object, a time-to-collision can be determined for each sensing and imaging device and each of the determined time-to-collisions can be utilized to determine a comprehensive time-to-collision that can provide greater confidence than a single calculation. Each of the respective time-to-collisions of an object for each sensing device can be given a respective weight for determining how much each respective time-to-collision determination should be relied on in determining the comprehensive time-to-collision.

[0007] Moreover, when dynamic expanded image is displayed on the rearview mirror display, the display may be toggled between displaying the dynamic expanded image and a mirror with typical reflective properties.

[0008] An embodiment contemplates a method of displaying a captured image on a display device of a driven vehicle. A scene exterior of the driven vehicle is captured by an at least one vision-based imaging device mounted on the driven vehicle. Objects are detected in the captured image. A time-to-collision is determined for each object detected in the captured image. Objects are sensed in a vicinity of the driven vehicle by sensing devices. A time-to-collision is determined for each respective object sensed by the sensing devices. A comprehensive time-to-collision is determined for each object. The comprehensive time-to-collision for each object is determined as a function of each of the determined time-to-collisions for each object. An image of the captured scene is generated by a processor. The image is dynamically expanded to include sensed objects in the image. Sensed objects are highlighted in the dynamically expanded image. The highlighted objects identify objects proximate to the driven vehicle that are potential collisions to the driven vehicle. The dynamically expanded image with highlighted objects and associated collective time-to-collisions are displayed for each highlighted object in the display device that is determined as a potential collision.

[0009] An embodiment contemplates a method of displaying a captured image on a display device of a driven vehicle. A scene exterior of the driven vehicle is captured by an at least one vision-based imaging device mounted on the driven vehicle. Objects are detected in the captured image. Objects in a vicinity of the driven vehicle are sensed by sensing devices. An image of the captured scene by a processor is generated. The image is dynamically expanded to include sensed objects in the image. Sensed objects are highlighted in the dynamically expanded image that are potential collisions to the driven vehicle. The dynamically expanded image is displayed with highlighted objects on the rearview mirror. The rearview mirror is switchable between displaying the dynamically expanded image and displaying mirror reflective properties.

BRIEF DESCRIPTION OF DRAWINGS

[0010] FIG. **1** is an illustration of a vehicle including a surround view vision-based imaging system.

[0011] FIG. **2** is an illustration for a pinhole camera model.

[0012] FIG. **3** is an illustration of a non-planar pin-hole camera model.

[0013] FIG. **4** is a block flow diagram utilizing cylinder image surface modeling.

[0014] FIG. **5** is a block flow diagram utilizing an ellipse image surface model.

[0015] FIG. **6** is a flow diagram of view synthesis for mapping a point from a real image to the virtual image.

[0016] FIG. **7** is an illustration of a radial distortion correction model.

[0017] FIG. **8** is an illustration of a severe radial distortion model.

[0018] FIG. **9** is a block diagram for applying view synthesis for determining a virtual incident ray angle based on a point on a virtual image.

[0019] FIG. **10** is an illustration of an incident ray projected onto a respective cylindrical imaging surface model.

[0020] FIG. **11** is a block diagram for applying a virtual pan/tilt for determining a ray incident ray angle based on a virtual incident ray angle.

[0021] FIG. **12** is a rotational representation of a pan/tilt between a virtual incident ray angle and a real incident ray angle.

[0022] FIG. **13** is a block diagram for displaying the captured images from one or more image capture devices on the rearview mirror display device.

[0023] FIG. **14** illustrates a block diagram of a dynamic rearview mirror display imaging system using a single camera.

[0024] FIG. **15** illustrates a flowchart for adaptive dimming and adaptive overlay of an image in a rearview mirror device.

[0025] FIG. **16** illustrates a flowchart of a first embodiment for identifying objects in a rearview mirror display device.

[0026] FIG. **17** is an illustration of rear view display device executing a rear cross traffic alert.

[0027] FIG. **18** is an illustration of a dynamic rearview display device executing a rear cross traffic alert.

[0028] FIG. **19** illustrates a flowchart of a second embodiment for identifying objects in a rearview mirror display device.

[0029] FIG. **20** is illustration of a dynamic image displayed on the dynamic rearview mirror device for the embodiment described in FIG. **19**.

[0030] FIG. **21** illustrates a flowchart of a third embodiment for identifying objects in a rearview mirror display device.

[0031] FIG. **22** illustrates a flowchart of the time to collision and image size estimation approach.

[0032] FIG. **23** illustrates an exemplary image captured by an object capture device at a first instance of time.

[0033] FIG. **24** illustrates an exemplary image captured by an image capture device at a second instance of time.

[0034] FIG. **25** illustrates a flowchart of the time to collision estimation approach through point motion estimation in the image plane.

[0035] FIG. **26** illustrates a flowchart of a fourth embodiment for identifying objects on the rearview mirror display device.

[0036] FIG. **27** is an interior passenger compartment illustrating the various output display devices.

[0037] FIG. **28** is a flowchart for switching displays on an output display device.

DETAILED DESCRIPTION

[0038] There is shown in FIG. **1**, a vehicle **10** traveling along a road. A vision-based imaging system **12** captures images of the road. The vision-based imaging system **12** captures images surrounding the vehicle based on the location of one or more vision-based capture devices. In the embodiments described herein, the vision-based imaging system captures images rearward of the vehicle, forward of the vehicle, and to the sides of the vehicle.

[0039] The vision-based imaging system **12** includes a front-view camera **14** for capturing a field-of-view (FOV) forward of the vehicle **10**, a rear-view camera **16** for capturing a FOV rearward of the vehicle, a left-side view camera **18** for capturing a FOV to a left side of the vehicle, and a right-side view camera **20** for capturing a FOV on a right side of the vehicle. The cameras **14-20** can be any camera suitable for the purposes described herein, many of which are known in the automotive art, that are capable of receiving light, or other radiation, and converting the light energy to electrical signals in a pixel format using, for example, charged coupled devices (CCD). The cameras **14-20** generate frames of image data at a certain data frame rate that can be stored for subsequent processing. The cameras **14-20** can be mounted within or on any suitable structure that is part of the vehicle **10**, such as bumpers, facie, grill, side-view mirrors, door panels, behind the windshield, etc., as would be well understood and appreciated by those skilled in the art. Image data from the cameras **14-20** is sent to a processor **22** that processes the image data to generate images that can be displayed on a review mirror display device **24**. It should be understood that a one camera solution is included (e.g., rearview) and that it is not necessary to utilize 4 different cameras as describe above.

[0040] The present invention utilizes the captured scene from the vision imaging based device **12** for detecting lighting conditions of the captured scene, which is then used to adjust a dimming function of the image display of the rearview mirror **24**. Preferably, a wide angle lens camera is utilized for capturing an ultra-wide FOV of a scene exterior of the vehicle, such a region represented by **26**. The vision imaging based device **12** focuses on a respective region of the captured image, which is preferably a region that includes the sky **28** as well as the sun, and high-beams from other vehicles at night. By focusing on the illumination intensity of the sky, the illumination intensity level of the captured scene can be determined. This objective is to build a synthetic image as taken from a virtual camera having an optical axis that is directed at the sky for generating a virtual sky view image. Once a sky view is generated from the virtual camera directed at the sky, a brightness of the scene may be determined. Thereafter, the image displayed through the rearview mirror **24** or any other display within the vehicle may be dynamically adjusted. In addition, a graphic image overlay may be projected onto the image display of the rearview mirror **24**. The image overlay replicates components of the vehicle (e.g., head rests, rear window trim, c-pillars) that includes line-based overlays (e.g., sketches) that would typically be seen by a driver when viewing a reflection through the rearview mirror having ordinary reflection properties. The image displayed by the graphic overlay may also be adjusted as to the brightness of the scene to maintain a desired translucency such that the graphic overlay does not interfere with the scene reproduced on the rearview mirror, and is not washed out.

[0041] In order to generate the virtual sky image based on the capture image of a real cameral, the captured image must be modeled, processed, and view synthesized for generating a virtual image from the real image. The following description details how this process is accomplished. The present invention uses an image modeling and de-warping process for both narrow FOV and ultra-wide FOV cameras that employs a simple two-step approach and offers fast processing times and enhanced image quality without utilizing radial distortion correction. Distortion is a deviation from rectilinear projection, a projection in which straight lines in a scene remain straight in an image. Radial distortion is a failure of a lens to be rectilinear.

[0042] The two-step approach as discussed above includes (1) applying a camera model to the captured image for projecting the captured image on a non-planar imaging surface and (2) applying a view synthesis for mapping the virtual image projected on to the non-planar surface to the real display image. For view synthesis, given one or more images of a specific subject taken from specific points with specific camera setting and orientations, the goal is to build a synthetic image as taken from a virtual camera having a same or different optical axis.

[0043] The proposed approach provides effective surround view and dynamic rearview mirror functions with an enhanced de-warping operation, in addition to a dynamic view synthesis for ultra-wide FOV cameras. Camera calibration as used herein refers to estimating a number of camera parameters including both intrinsic and extrinsic parameters. The intrinsic parameters include focal length, image center (or principal point), radial distortion parameters, etc. and extrinsic parameters include camera location, camera orientation, etc.

[0044] Camera models are known in the art for mapping objects in the world space to an image sensor plane of a camera to generate an image. One model known in the art is referred to as a pinhole camera model that is effective for modeling the image for narrow FOV cameras. The pinhole camera model is defined as:

$$S\underbrace{\begin{bmatrix} u \\ v \\ 1 \end{bmatrix}}_{m} = \begin{bmatrix} \underbrace{\begin{matrix} f_u & Y & u_c \\ 0 & f_v & v_c \\ 0 & 0 & 1 \end{matrix}}_{A} \end{bmatrix} \begin{bmatrix} \underbrace{r_1 \quad r_2 \quad r_3 \quad t}_{[R \quad t]} \end{bmatrix} \underbrace{\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}}_{M} \tag{1}$$

[0045] FIG. **2** is an illustration **30** for the pinhole camera model and shows a two dimensional camera image plane **32** defined by coordinates u, v, and a three dimensional object space **34** defined by world coordinates x, y, and z. The distance from a focal point C to the image plane **32** is the focal length f of the camera and is defined by focal length f_u and f_v. A perpendicular line from the point C to the principal point of the image plane **32** defines the image center of the plane **32** designated by u_0, v_0. In the illustration **30**, an object point M in the object space **34** is mapped to the image plane **32** at point m, where the coordinates of the image point m is u_c, v_c.

[0046] Equation (1) includes the parameters that are employed to provide the mapping of point M in the object space **34** to point m in the image plane **32**. Particularly, intrinsic parameters include f_u, f_v, u_c, v_c and γ and extrinsic parameters include a 3 by 3 matrix R for the camera rotation and a 3 by 1 translation vector t from the image plane **32** to the object space **34**. The parameter γ represents a skewness of the two image axes that is typically negligible, and is often set to zero.

[0047] Since the pinhole camera model follows rectilinear projection which a finite size planar image surface can only cover a limited FOV range (<<180° FOV), to generate a cylindrical panorama view for an ultra-wide (~180° FOV) fisheye camera using a planar image surface, a specific camera model must be utilized to take horizontal radial distortion into account. Some other views may require other specific camera modeling, (and some specific views may not be able to be generated). However, by changing the image plane to a non-planar image surface, a specific view can be easily generated by still using the simple ray tracing and pinhole camera model. As a result, the following description will describe the advantages of utilizing a non-planar image surface.

[0048] The rearview mirror display device **24** (shown in FIG. **1**) outputs images captured by the vision-based imaging system **12**. The images may be altered images that may be converted to show enhanced viewing of a respective portion of the FOV of the captured image. For example, an image may be altered for generating a panoramic scene, or an image may be generated that enhances a region of the image in the direction of which a vehicle is turning. The proposed approach as described herein models a wide FOV camera with a concave imaging surface for a simpler camera model without radial distortion correction. This approach utilizes virtual view synthesis techniques with a novel camera imaging surface modeling (e.g., light-ray-based modeling). This technique has a variety of applications of rearview camera applications that include dynamic guidelines, 360 surround view camera system, and dynamic rearview mirror feature. This technique simulates various image effects through the simple camera pin-hole model with various camera imaging surfaces. It should be understood that other models, including traditional models, can be used aside from a camera pin-hole model.

[0049] FIG. **3** illustrates a preferred technique for modeling the captured scene **38** using a non-planar image surface. Using the pin-hole model, the captured scene **38** is projected onto a non-planar image **49** (e.g., concave surface). No radial distortion correction is applied to the projected image since the image is being displayed on a non-planar surface.

[0050] A view synthesis technique is applied to the projected image on the non-planar surface for de-warping the image. In FIG. **3**, image de-warping is achieved using a concave image surface. Such surfaces may include, but are not limited to, a cylinder and ellipse image surfaces. That is, the captured scene is projected onto a cylindrical like surface using a pin-hole model. Thereafter, the image projected on the cylinder image surface is laid out on the flat in-vehicle image display device. As a result, the parking space which the vehicle is attempting to park is enhanced for better viewing for assisting the driver in focusing on the area of intended travel.

[0051] FIG. **4** illustrates a block flow diagram for applying cylinder image surface modeling to the captured scene. A captured scene is shown at block **46**. Camera modeling **52** is applied to the captured scene **46**. As described earlier, the camera model is preferably a pin-hole camera model, however, traditional or other camera modeling may be used. The captured image is projected on a respective surface using the pin-hole camera model. The respective image surface is a cylindrical image surface **54**. View synthesis **42** is performed by mapping the light rays of the projected image on the cylindrical surface to the incident rays of the captured real image to generate a de-warped image. The result is an enhanced view of the available parking space where the parking space is centered at the forefront of the de-warped image **51**.

[0052] FIG. **5** illustrates a flow diagram for utilizing an ellipse image surface model to the captured scene utilizing the pin-hole model. The ellipse image model **56** applies greater resolution to the center of the capture scene **46**. Therefore, as shown in the de-warped image **57**, the objects at the center forefront of the de-warped image are more enhanced using the ellipse model in comparison to FIG. **5**.

[0053] Dynamic view synthesis is a technique by which a specific view synthesis is enabled based on a driving scenario of a vehicle operation. For example, special synthetic modeling techniques may be triggered if the vehicle is in driving in a parking lot versus a highway, or may be triggered by a proximity sensor sensing an object to a respective region of the vehicle, or triggered by a vehicle signal (e.g., turn signal, steering wheel angle, or vehicle speed). The special synthesis modeling technique may be to apply respective shaped models to a captured image, or apply virtual pan, tilt, or directional zoom depending on a triggered operation.

[0054] FIG. **6** illustrates a flow diagram of view synthesis for mapping a point from a real image to the virtual image. In block **61**, a real point on the captured image is identified by coordinates u_{real} and v_{real} which identify where an incident ray contacts an image surface. An incident ray can be represented by the angles (θ,ϕ), where θ is the angle between the incident ray and an optical axis, and ϕ is the angle between the x axis and the projection of the incident ray on the x-y plane. To determine the incident ray angle, a real camera model is pre-determined and calibrated.

[0055] In block **62**, the real camera model is defined, such as the fisheye model (r_d=func(θ) and ϕ). That is, the incident ray as seen by a real fish-eye camera view may be illustrated as follows:

$$\text{Incident ray} \rightarrow \begin{bmatrix} \theta\text{: angle between incident} \\ \text{ray and optical axis} \\ \varphi\text{: angle between } x_{c1} \text{ and} \\ \text{incident ray projection} \\ \text{on the } x_{c1}-y_{c1} \text{ plane} \end{bmatrix} \rightarrow \tag{2}$$

$$\begin{bmatrix} r_d = func(\theta) \\ \varphi \end{bmatrix} \rightarrow \begin{bmatrix} u_{c1} = r_d \cdot \cos(\varphi) \\ v_{c1} = r_d \cdot \sin(\varphi) \end{bmatrix}$$

where x_{c1}, y_{c1}, and z_{c1} are the camera coordinates where z_{c1} is a camera/lens optical axis that points out the camera, and where u_{c1} represents u_{real} and v_{c1} represents v_{real}. A radial distortion correction model is shown in FIG. **7**. The radial distortion model, represented by equation (3) below, sometimes referred to as the Brown-Conrady model, that provides a correction for non-severe radial distortion for objects imaged on an image plane **72** from an object space **74**. The focal length f of the camera is the distance between point **76** and the image center where the lens optical axis intersects with the image plane **72**. In the illustration, an image location r_0 at the intersection of line **70** and the image plane **72** represents a virtual image point m_0 of the object point M if a pinhole camera model is used. However, since the camera image has radial distortion, the real image point m is at location r_d, which is the intersection of the line **78** and the image plane **72**. The values r_0 and r_d are not points, but are the radial distance from the image center u_p, v_0 to the image points m_0 and m.

$$r_d=r_0(1+k_1\cdot r_0^2+k_2\cdot r_0^4+k_2\cdot r_0^6+\ldots \tag{3}$$

[0056] The point r_0 is determined using the pinhole model discussed above and includes the intrinsic and extrinsic parameters mentioned. The model of equation (3) is an even order polynomial that converts the point r_0 to the point r_d in the image plane **72**, where k is the parameters that need to be determined to provide the correction, and where the number of the parameters k define the degree of correction accuracy. The calibration process is performed in the laboratory environment for the particular camera that determines the parameters k. Thus, in addition to the intrinsic and extrinsic parameters for the pinhole camera model, the model for equation (3) includes the additional parameters k to determine the radial distortion. The non-severe radial distortion correction provided by the model of equation (3) is typically effective for wide FOV cameras, such as 135° FOV cameras. However, for ultra-wide FOV cameras, i.e., 180° FOV, the radial distortion is too severe for the model of equation (3) to be effective. In other words, when the FOV of the camera exceeds some value, for example, 140°-150°, the value r_0 goes to infinity when the angle θ approaches 90°. For ultra-wide FOV cameras, a severe radial distortion correction model shown in equation (4) has been proposed in the art to provide correction for severe radial distortion.

[0057] FIG. **8** illustrates a fisheye model which shows a dome to illustrate the FOV. This dome is representative of a fisheye lens camera model and the FOV that can be obtained by a fisheye model which is as large as 180 degrees or more. A fisheye lens is an ultra wide-angle lens that produces strong visual distortion intended to create a wide panoramic or hemispherical image. Fisheye lenses achieve extremely wide angles of view by forgoing producing images with straight lines of perspective (rectilinear images), opting instead for a special mapping (for example: equisolid angle), which gives images a characteristic convex non-rectilinear appearance This model is representative of severe radial distortion due which is shown in equation (4) below, where equation (4) is an odd order polynomial, and includes a technique for providing a radial correction of the point r_0 to the point r_d in the image plane **79**. As above, the image plane is designated by the coordinates u and v, and the object space is designated by the world coordinates x, y, z. Further, θ is the incident angle between the incident ray and the optical axis. In the illustration, point p' is the virtual image point of the object point M using the pinhole camera model, where its radial distance r_0 may go to infinity when θ approaches 90°. Point p at radial distance r is the real image of point M, which has the radial distortion that can be modeled by equation (4).

[0058] The values q in equation (4) are the parameters that are determined. Thus, the incidence angle θ is used to provide the distortion correction based on the calculated parameters during the calibration process.

$$r_d=q_1\cdot\theta_0+q_2\cdot\theta_0^3+q_3\cdot\theta_0^5+\ldots \tag{4}$$

Various techniques are known in the art to provide the estimation of the parameters k for the model of equation (3) or the parameters q for the model of equation (4). For example, in one embodiment a checker board pattern is used and multiple images of the pattern are taken at various viewing angles, where each corner point in the pattern between adjacent squares is identified. Each of the points in the checker board pattern is labeled and the location of each point is identified in both the image plane and the object space in world coordinates. The calibration of the camera is obtained through parameter estimation by minimizing the error distance between the real image points and the reprojection of 3D object space points.

[0059] In block **63**, a real incident ray angle (θ_{real}) and (ϕ_{real}) are determined from the real camera model. The corresponding incident ray will be represented by a (θ_{real}, ϕ_{real}).

[0060] In block **64**, a virtual incident ray angle θ_{virt} and corresponding ϕ_{virt} is determined. If there is no virtual tilt and/or pan, then (θ_{virt},ϕ_{virt}) will be equal to (θ_{real},ϕ_{real}). If virtual tilt and/or pan are present, then adjustments must be made to determine the virtual incident ray. Discussion of the virtual incident ray will be discussed in detail later.

[0061] Referring again to FIG. **6**, in block **65**, once the incident ray angle is known, then view synthesis is applied by utilizing a respective camera model (e.g., pinhole model) and respective non-planar imaging surface (e.g., cylindrical imaging surface).

[0062] In block **66**, the virtual incident ray that intersects the non-planar surface is determined in the virtual image. The coordinate of the virtual incident ray intersecting the virtual non-planar surface as shown on the virtual image is represented as (u_{virt},v_{virt}). As a result, a mapping of a pixel on the virtual image (u_{virt},v_{virt}) corresponds to a pixel on the real image (u_{real},v_{real}).

[0063] It should be understood that while the above flow diagram represents view synthesis by obtaining a pixel in the real image and finding a correlation to the virtual image, the reverse order may be performed when utilizing in a vehicle. That is, every point on the real image may not be utilized in the virtual image due to the distortion and focusing only on a respective highlighted region (e.g., cylindrical/elliptical shape). Therefore, if processing takes place with respect to these points that are not utilized, then time is wasted in processing pixels that are not utilized. Therefore, for an in-vehicle processing of the image, the reverse order is performed. That is, a location is identified in a virtual image and the corresponding point is identified in the real image. The following describes the details for identifying a pixel in the virtual image and determining a corresponding pixel in the real image.

[0064] FIG. **9** illustrates a block diagram of the first step for obtaining a virtual coordinate (u_{virt} v_{virt}) and applying view synthesis for identifying virtual incident angles (θ_{virt},ϕ_{virt}). FIG. **10** represents an incident ray projected onto a respective cylindrical imaging surface model. The horizontal projection of incident angle θ is represented by the angle α. The formula for determining angle α follows the equidistance projection as follows:

$$\frac{u_{virt} - u_0}{f_u} = \alpha \tag{5}$$

where u_{virt} is the virtual image point u-axis (horizontal) coordinate, f_u is the u direction (horizontal) focal length of the camera, and u_0 is the image center u-axis coordinate.

[0065] Next, the vertical projection of angle θ is represented by the angle β. The formula for determining angle β follows the rectilinear projection as follows:

$$\frac{v_{virt} - v_0}{f_v} = \tan\beta \tag{6}$$

where v_{virt} is the virtual image point v-axis (vertical) coordinate, f_v is the v direction (vertical) focal length of the camera, and v_0 is the image center v-axis coordinate.

[0066] The incident ray angles can then be determined by the following formulas:

$$\begin{cases} \theta_{virt} = \arccos(\cos(\alpha)\cdot\cos(\beta)) \\ \varphi_{virt} = \arctan(\sin(\alpha)\cdot\tan(\beta)) \end{cases} \tag{7}$$

[0067] As described earlier, if there is no pan or tilt between the optical axis of the virtual camera and the real camera, then the virtual incident ray (θ_{virt},ϕ_{virt}) and the real incident ray (θ_{real},ϕ_{real}) are equal. If pan and/or tilt are present, then compensation must be made to correlate the projection of the virtual incident ray and the real incident ray.

[0068] FIG. **11** illustrates the block diagram conversion from virtual incident ray angles to real incident ray angles when virtual tilt and/or pan are present. Since optical axis of the virtual cameras will be focused toward the sky and the real camera will be substantially horizontal to the road of travel, a difference is the axes requires a tilt and/or pan rotation operation.

[0069] FIG. **12** illustrates a comparison between axes changes from virtual to real due to virtual pan and/or tilt rotations. The incident ray location does not change, so the correspondence virtual incident ray angles and the real incident ray angle as shown is related to the pan and tilt. The incident ray is represented by the angles (θ,ϕ), where θ is the angle between the incident ray and the optical axis (represented by the z axis), and ϕ is the angle between x axis and the projection of the incident ray on the x-y plane.

[0070] For each determined virtual incident ray (θ_{virt},ϕ_{virt}), any point on the incident ray can be represented by the following matrix:

$$P_{virt} = \rho\cdot\begin{bmatrix} \sin(\theta_{virt})\cdot\cos(\theta_{virt}) \\ \sin(\theta_{virt})\cdot\sin(\theta_{virt}) \\ \cos(\theta\mathrm{virt}) \end{bmatrix} \tag{8}$$

where ρ is the distance of the point form the origin.

[0071] The virtual pan and/or tilt can be represented by a rotation matrix as follows:

$$R_{rot} = R_{tilt}\cdot R_{pan} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\beta) & \sin(\beta) \\ 0 & -\sin(\beta) & \cos(\beta) \end{bmatrix}\cdot\begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix} \tag{9}$$

where α is the pan angle, and β is the tilt angle.

[0072] After the virtual pan and/or tilt rotation is identified, the coordinates of a same point on the same incident ray (for the real) will be as follows:

$$P_{real} = R_{rot}\cdot R_{virt} - \rho\cdot R_{rot}\begin{bmatrix} \sin(\theta_{virt})\cdot\cos(\theta_{virt}) \\ \sin(\theta_{virt})\cdot\sin(\theta_{virt}) \\ \cos(\theta\mathrm{virt}) \end{bmatrix} = \rho\begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}, \tag{10}$$

[0073] The new incident ray angles in the rotated coordinates system will be as follows:

$$\theta_{real} = \arctan\left(\frac{\sqrt{a_1^2 + a_2^2}}{a_3}\right), \phi = \mathrm{real} = \arctan\left(\frac{a_2}{a_1}\right). \tag{11}$$

As a result, a correspondence is determined between (θ_{virt}, ϕ_{virt}) and (θ_{real},ϕ_{real}) when tilt and/or pan is present with respect to the virtual camera model. It should be understood that that the correspondence between (θ_{virt},ϕ_{virt}) and (θ_{real}, ϕ_{real}) is not related to any specific point at distance ρ on the incident ray. The real incident ray angle is only related to the virtual incident ray angles ($\theta_{virt}, \phi_{virt}$) and virtual pan and/or tilt angles α and β.

[0074] Once the real incident ray angles are known, the intersection of the respective light rays on the real image may be readily determined as discussed earlier. The result is a mapping of a virtual point on the virtual image to a corresponding point on the real image. This process is performed for each point on the virtual image for identifying corresponding point on the real image and generating the resulting image.

[0075] FIG. **13** illustrates a block diagram of the overall system diagrams for displaying the captured images from one or more image capture devices on the rearview mirror display device. A plurality of image capture devices are shown generally at **80**. The plurality of image capture devices **80** includes at least one front camera, at least one side camera, and at least one rearview camera.

[0076] The images by the image capture devices **80** are input to a camera switch. The plurality of image capture devices **80** may be enabled based on the vehicle operating conditions **81**, such as vehicle speed, turning a corner, or backing into a parking space. The camera switch **82** enables one or more cameras based on vehicle information **81** communicated to the camera switch **82** over a communication bus, such as a CAN bus. A respective camera may also be selectively enabled by the driver of the vehicle.

[0077] The captured images from the selected image capture device(s) are provided to a processing unit **22**. The processing unit **22** processes the images utilizing a respective camera model as described herein and applies a view synthesis for mapping the capture image onto the display of the rearview mirror device **24**.

[0078] A mirror mode button **84** may be actuated by the driver of the vehicle for dynamically enabling a respective mode associated with the scene displayed on the rearview mirror device **24**. Three different modes include, but are not limited to, (1) dynamic rearview mirror with review cameras; (2) dynamic mirror with front-view cameras; and (3) dynamic review mirror with surround view cameras.

[0079] Upon selection of the mirror mode and processing of the respective images, the processed images are provided to the rearview image device **24** where the images of the captured scene are reproduced and displayed to the driver of the vehicle via the rearview image display device **24**. It should be understood that any of the respective cameras may be used to capture the image for conversion to a virtual image for scene brightness analysis.

[0080] FIG. **14** illustrates an example of a block diagram of a dynamic rearview mirror display imaging system using a single camera. The dynamic rearview mirror display imaging system includes a single camera **90** having wide angle FOV functionality. The wide angle FOV of the camera may be greater than, equal to, or less than 180 degrees viewing angle.

[0081] If only a single camera is used, camera switching is not required. The captured image is input to the processing unit **22** where the captured image is applied to a camera model. The camera model utilized in this example includes an ellipse camera model; however, it should be understood that other camera models may be utilized. The projection of the ellipse camera model is meant to view the scene as though the image is wrapped about an ellipse and viewed from within. As a result, pixels that are at the center of the image are viewed as being closer as opposed to pixels located at the ends of the captured image. Zooming in the center of the image is greater than at the sides.

[0082] The processing unit **22** also applies a view synthesis for mapping the captured image from the concave surface of the ellipse model to the flat display screen of the rearview mirror.

[0083] The mirror mode button **84** includes further functionality that allows the driver to control other viewing options of the rearview mirror display **24**. The additional viewing options that may be selected by driver includes: (1) Mirror Display Off; (2) Mirror Display On With Image Overlay; and (3) Mirror Display On Without Image Overlay.

[0084] "Mirror Display Off" indicates that the image captured by the capture image device that is modeled, processed, displayed as a de-warped image is not displayed onto the rearview mirror display device. Rather, the rearview mirror functions identical as a mirror displaying only those objects captured by the reflection properties of the mirror.

[0085] The "Mirror Display On With Image Overlay" indicates that the captured image by the capture image device that is modeled, processed, and projected as a de-warped image is displayed on the image capture device **24** illustrating the wide angle FOV of the scene. Moreover, an image overlay **92** (shown in FIG. **15**) is projected onto the image display of the rearview mirror **24**. The image overlay **92** replicates components of the vehicle (e.g., head rests, rear window trim, c-pillars) that would typically be seen by a driver when viewing a reflection through the rearview mirror having ordinary reflection properties. This image overlay **92** assist the driver in identifying relative positioning of the vehicle with respect to the road and other objects surrounding the vehicle. The image overlay **92** is preferably translucent or thin sketch lines representing the vehicle key elements to allow the driver to view the entire contents of the scene unobstructed.

[0086] The "Mirror Display On Without Image Overlay" displays the same captured images as described above but without the image overlay. The purpose of the image overlay is to allow the driver to reference contents of the scene relative to the vehicle; however, a driver may find that the image overlay is not required and may select to have no image overlay in the display. This selection is entirely at the discretion of the driver of the vehicle.

[0087] Based on the selection made to the mirror button mode **84**, the appropriate image is presented to the driver via the rearview mirror in block **24**. It should be understood that if more than one camera is utilized, such as a plurality of narrow FOV cameras, where each of the images must be integrated together, then image stitching may be used. Image stitching is the process of combining multiple images with overlapping regions of the images FOV for producing a segmented panoramic view that is seamless. That is, the combined images are combined such that there are no noticeable boundaries as to where the overlapping regions have been merged. After image stitching has been performed, the stitched image is input to the processing unit for applying camera modeling and view synthesis to the image.

[0088] In systems were just an image is reflected by a typical rearview mirror or a captured image is obtained where dynamic enhancement is not utilized such as a simple camera with no fisheye or a camera having a narrow FOV, objects that are possible a safety issue or could by on a collision with the vehicle are not captured in the image. Other sensors on the vehicle may in fact detect such objects, but displaying a warning and identifying the image in the object is an issue. Therefore, by utilizing a captured image and utilizing a dynamic display where a wide FOV is obtained either by a fisheye lens, image stitching, or digital zoom, an object can be illustrated on the image. Moreover, symbols such a parking assist symbols and object outlines for collision avoidance may be overlaid on the object.

[0089] FIG. **16** illustrates a flowchart of first embodiment for identifying objects on the dynamic rearview mirror display device. While the embodiments discussed herein describe the display of the image on the rearview mirror device, it is understood that the display device is not limited to the rearview mirror and may include any other display device in the vehicle. Blocks **110-116** represent various sensing devices for sensing objects exterior of the vehicle, such as vehicles, pedestrians, bikes, and other moving and stationary objects. For example, block **110** is a side blind zone alert sensor (SBZA) sensing system for sensing objects in a blind spot of the vehicle; block **112** is a parking assist (PA) ultrasonic sensing system for sensing pedestrians; block **44** is a rear cross traffic alert (RTCA) system for detecting a vehicle in a rear crossing path that is transverse to the driven vehicle; and block **116** is a rearview camera for capturing scenes exterior of the vehicle. In FIG. **16**, an image is captured and is displayed on the rearview image display device. Any of the objects detected by any of the systems shown in blocks **110-116** are cooperatively analyzed and identified. Any of the alert symbols utilized by any of the sensing systems **110-114** may be processed and those symbols may be overlaid on the dynamic image in block **129**. The dynamic image and the overlay symbols are then displayed on the rearview display device in block **120**.

[0090] In typical systems, as shown in FIG. **17**, a rear crossing object approaching as detected by the RCTA system is not yet seen on an image captured by a narrow FOV imaging device. However, the object that cannot be seen in the image is identified by the RCTA symbol **122** for identifying an object identified by one of the sensing systems but is not in the image yet.

[0091] FIG. **18** illustrates a system utilizing a dynamic rearview display. In FIG. **18**, a vehicle **124** is captured approaching from the right side of the captured image. Objects are captured by the imaging device using a wide FOV captured image or the image may be stitched together using multiple images captured by more than one image capture device. Due to the distortion of the image at the far ends of the image, in addition to the speed of the vehicle **124** as it travels along the road of travel that is transverse to the travel path of the driven vehicle, the vehicle **124** may not be readily noticeable or the speed of the vehicle may not be readily predictable by the driver. In cooperation with the RCTA system, to assist the driver in identifying the vehicle **124** that could be on a collision course if both vehicles were to proceed into the intersection, an alert symbol **126** is overlaid around the vehicle **124** which has been perceived by the RCTA system as a potential threat. Other vehicle information may be included as part of the alert symbol that includes, vehicle speed, time-to-collision, course heading may be overlaid around the vehicle **124**. The symbol **122** is overlaid across the vehicle **124** or other object as may be required to provide notification to the driver. The symbol does not need to identify the exact location or size of the object, but rather just provide notification of the object in the image to the driver.

[0092] FIG. **19** illustrates a flowchart of a second embodiment for identifying objects on the rearview mirror display device. Similar reference numbers will be utilized throughout for already introduced devices and systems. Blocks **110-116** represent various sensing devices such as SBZA, PA, RTCA, and a rearview camera. In block **129**, a processing unit provides an object overlay onto the image. The object overlay is an overlay that identifies both the correct location and size of an object as opposed to just placing a same sized symbol over the object as illustrated in FIG. **18**. In block **120**, the rearview display device displays the dynamic image with the object overlay symbols and collective image is then displayed on the rearview display device in block **120**.

[0093] FIG. **20** is an illustration of a dynamic image displayed on the dynamic rearview mirror device. Object overlays **132-138** identify vehicles proximate to the driven vehicle that have been identified by one of the sensing systems that may be a potential collision to a driven vehicle if a driving maneuver is made and the driver of the driven vehicle is not aware of the presence of any of those objects. As shown, each object overlay is preferably represented as a rectangular box having four corners. Each of the corners designate a respective point. Each point is positioned so that when the rectangle is generated, the entire vehicle is properly positioned within the rectangular shape of the object overlay. As a result, the size of the rectangular image overlay assists the driver in identifying not only the correct location of the object but provides awareness as to the relative distance to the driven vehicle. That is, for objects that are closer to the driven vehicle, the image overly such as objects **132** and **134** will be larger, whereas, for objects that are further away from the driven vehicle, the image overlay such as object **136** will appear smaller. Moreover, redundant visual confirmation can be used with the image overlay to generate awareness condition of an object. For example, awareness notification symbols, such as symbols **140** and **142**, can be displayed cooperatively with the object overlays **132** and **138**, respectively, to provide a redundant warning. In this example, symbols **140** and **142** provide further details as to why the object is being highlighted and identified. Such symbols can be utilized in cooperation with alerts from blind spot detection systems, lane departure warning systems, and lane change assist systems.

[0094] Image overlay **138** generates a vehicle boundary of the vehicle. Since the virtual image is generated less any of only the objects and scenery exterior of the vehicle, the virtual image captured will not capture any exterior trim components of the vehicle. Therefore, image overlay **138** is provided that generates a vehicle boundary as to where the boundaries of the vehicle would be located had they been shown in the captured image.

[0095] FIG. **21** illustrates a flowchart of third embodiment for identifying objects on the rearview mirror display device by estimating a time to collision base on an inter-frame object size and location expansion of an object overlay, and illustrate the warning on the dynamic rearview display device. In block **116**, images are captured by an image capture device.

[0096] In block **144**, various systems are used to identify objects captured in the captured image. Such objects include, but not limited to, vehicles from devices described herein, lanes of the road based on lane centering systems, pedestrians from pedestrian awareness systems, parking assist system, and poles or obstacles from various sensing systems/devices.

[0097] A vehicle detection system estimates the time to collision herein. The time to collision and object size estimation may be determined using an image based approach or may be determined using a point motion estimation in the image plane, which will be described in detail later.

[0098] The time to collision may be determined from various devices. Lidar is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. Lidar provides object range data directly. A difference between a range change is the relative speed of the object. Therefore, the time to collision may be determined by the change in range divided by the change in relative speed.

[0099] Radar is an object detection technology that uses radio waves to determine the range and speed of objects. Radar provides an object's relative speed and range directly. The time to collision may be determined as function of the range divided by the relative speed.

[0100] Various other devices may be used in combination to determine whether a vehicle is on a collision course with a remote vehicle in a vicinity of the driven vehicle. Such devices include lane departure warning systems which indicate a lane change may be occurring during a non-activation of a turn signal. If the vehicle is departing a lane toward a lane of the detected remote vehicle, then a determination may be made that a time to collision should be determined and the driver made aware. Moreover, pedestrian detection devices, parking assist devices, and clear path detection systems may be used to detect objects in the vicinity for which a time to collision should be determined.

[0101] In block **146**, the objects with object overlay are generated along with the time to collision for each object.

[0102] In block **120**, the results are displayed on the dynamic rearview display mirror.

[0103] FIG. **22** is a flowchart of the time to collision and image size estimation approach as described in block **144** of FIG. **21**. In block **150**, an image is generated and an object is detected at time t-1. The captured image and image overlay is shown in FIG. **23** at **156**. In block **151**, an image is generated and the object is detected at time t. The captured image and image overlay is shown in FIG. **24** at block **158**.

[0104] In block **152**, the object size, distance, and vehicle coordinate is recorded. This is performed by defining a window overlay for the detected object (e.g., the boundary of the object as defined by the rectangular box). The rectangular boundary should encase the each element of the vehicle that can be identified in the captured image. Therefore, the boundaries should be close to those outermost exterior portions of the vehicle without creating large gaps between an outermost exterior component of the vehicle and the boundary itself.

[0105] To determine an object size, an object detection window is defined. This can be determined by estimating the following parameters:

$def{:}win_t^{det}{:}(uW_t,vH_t,vB_t)$:object detection window size and location (on image) at time t

where

uW_t:detection—window width, vH_t:detection—window height,

and vB_t:detection—window bottom.

[0106] Next, the object size and distance represented as vehicle coordinates is estimated by the following parameters:

$def{:}x_t=(w_t^o,h_t^o,d_t^o)$ is the object size and distance (observed) in vehicle coordinates

where w_t^o is the object width(observed), h_t^o is the object height(observed), and d_t^o is the object distance(observed) at time t.

[0107] Based on camera calibration, the (observed) object size and distance X_t can be determined from the in-vehicle detection window size and location win_t^{det} as represented by the following equation:

$$win_t^{det}\colon (uW_t,\ vW_t,\ vB_t)\xrightarrow{CamCalib}X_t\colon (w_t^O,\ h_t^O,\ d_t^O)$$

[0108] In block **153**, the object distance and relative speed of the object is calculated as components in Y_t. In this step, the output Y_t is determined which represents the estimated object parameters (size, distance, velocity) at time t. This is represented by the following definition:

$def{:}Y_t=(w_t^e,h_t^e,d_t^e,v_t)$

where w_t^e, h_t^e, d_t^e are estimated object size and distance, and v_t is the object relative speed at time t.

[0109] Next, a model is used to estimate object parameters and a time-to-collision (TTC) and is represented by the following equation:

$Y_t=f(X_1,X_{t-1},X_{t-2},\ldots,X_{t-n})$

[0110] A more simplified example of the above function f can be represented as follows:

$$\text{object size: } w_t^e=\frac{\sum_{i=0}^{n}w_{t-i}^O}{n+1},\ h_t^e=\frac{\sum_{i=0}^{n}h_{t-i}^O}{n+1},$$

$$\text{object distance: } d_t^e=d_t^o$$

$$\text{object relative speed: } v_t=\Delta d/\Delta t=(d_t^e-d_{t-1}^e)/\Delta t$$

[0111] In block **154**, the time to collision is derived using the above formulas which is represented by the following formula:

$TTC{:}TTC_t=d_t^e/v_t$

[0112] FIG. **25** is a flowchart of the time to collision estimation approach through point motion estimation in the image plane as described in FIG. **21**. In block **160**, an image is generated and an object size and point location is detected at time t-1. The captured image and image overlay is shown generally by **156** in FIG. **23**. In block **161**, an image is generated and an object size and point location is detected at time t. The captured image and image overlay is shown generally by **158** in FIG. **24**.

[0113] In block **162**, changes to the object size and to the object point location are determined. By comparing where an identified point in a first image is relative to the same point in another captured image where temporal displacement has occurred, the relative change in the location using the object size can be used to determine the time to collision.

[0114] In block **163**, the time to collision is determined is based on the occupancy of the target in the majority of the screen height.

[0115] To determine the change in height and width and corner points of the object overlay boundary, the following technique is utilized. The following parameters are defined:

[0116] w_t is the object width at time t,

[0117] h_t is the object height at time t,

[0118] p_t^i is the corner points, i=1, 2, 3, or 4 at time t.

The changes to the parameters based on a time lapse is represented by the following equations:

$$\Delta w_t = w_t - w_{t-1},$$

$$\Delta h_t = hw_t - h_{t-1},$$

$$\Delta x(p_t^i) = x(p_t^i) - x(p_{t-1}^i), \Delta y(p_i^i) = y(p_t^i) - y(p_{t-1}^i)$$

where

$$w_t = 0.5*(x(p_t^1) - x(p_t^2)) + 0.5*(x(p_t^3) - x(p_t^4)),$$

$$h_t = 0.5*(y(p_t^2) - y(p_t^4)) + 0.5*(y(p_t^3) - y(p_t^1)).$$

The following estimates are defined by f_w, f_h, f_x, f_y:

$$\Delta w_{t+1} = f_w(\Delta w_t, \Delta w_{t-1}, \Delta w_{t-2}, \ldots),$$

$$\Delta h_{t+1} = f_h(\Delta h_t, \Delta h_{t-1}, \Delta h_{t-2}, \ldots),$$

$$\Delta x_{t+1} = f_x(\Delta x_t, \Delta x_{t-1}, \Delta x_{t-2}, \ldots),$$

$$\Delta y_{t+1} = f_y(\Delta y_t, \Delta y_{t-1}, \Delta y_{t-2}, \ldots),$$

The TTC can be determined using the above variables Δw_{t+1}, Δh_{t+1}, Δx_{t+1} and, Δy_{t+1} with a function f_{TCC} which is represented by the following formula:

$$TTC_{t+1} = f_{TCC}(\Delta w_{t+1}, \Delta h_{t+1}, \Delta x_{t+1}, \Delta y_{t+1} \ldots).$$

[0119] FIG. **26** illustrates a flowchart of a fourth embodiment for identifying objects on the rearview mirror display device. Similar reference numbers will be utilized throughout for already introduced devices and systems. Blocks **110-116** represent various sensing devices such as SBZA, PA, RTCA, and a rearview camera.

[0120] In block **164**, a sensor fusion technique is applied to the results of each of the sensors fusing the objects of images detected by the image capture device with the objects detected in other sensing systems. Sensor fusion allows the outputs from at least two obstacle sensing devices to be performed at a sensor level. This provides richer content of information. Both detection and tracking of identified obstacles from both sensing devices is combined. The accuracy in identifying an obstacle at a respective location by fusing the information at the sensor level is increased in contrast to performing detection and tracking on data from each respective device first and then fusing the detection and tracking data thereafter. It should be understood that this technique is only one of many sensor fusion techniques that can be used and that other sensor fusion techniques can be applied without deviating from the scope of the invention.

[0121] In block **166**, the object detection results from the sensor fusion technique are identified in the image and highlighted with an object image overlay (e.g., Kalaman filtering, Condensation filtering).

[0122] In block **120**, the highlighted object image overlay are displayed on the dynamic rearview mirror display device.

[0123] FIG. **27** is an interior compartment of a vehicle illustrating the various methods in which information the dynamic enhanced image including TTC may be displayed to a driver of the vehicle. It should be understood that the various display devices as shown may be utilized solely in the vehicle or in combination with one another.

[0124] An interior passenger compartment is shown generally at **200**. An instrument panel **202** includes a display device **204** for displaying the dynamically enhanced image. The instrument panel may further include a center console stack **206** that includes the display device **204** as well as other electronic devices such as multimedia controls, navigation system, or HVAC controls.

[0125] The dynamically enhanced image may be displayed on a heads-up-display HUD **208**. The TTC may also be projected as part of the HUD **208** for alerting the driver to a potential collision. Displays such as those shown in FIG. **18** and FIG. **20** may be displayed as part of the HUD **208**. The HUD **208** is a transparent display that projects data on a windshield **210** without requiring users to look away from a road of travel. The dynamic enhanced image is projected in a manner that does not interfere with the driver viewing view of images exterior of the vehicle.

[0126] The dynamically enhanced image may further be displayed on a rearview mirror display **212**. The rearview mirror display **212** when not projecting the dynamically enhanced image may be utilized as a customary rearview reflective mirror having usual mirror reflection properties. The rearview mirror display **212** may be switched manually or autonomously between the dynamically enhanced image projected on the rearview mirror display and a reflective mirror.

[0127] A manual toggling between the dynamically enhanced display and the reflective mirror may be actuated by the driver using a designated button **214**. The designated button **214** may be disposed on the steering wheel **216** or the designated button **214** may be disposed on the rearview mirror display **212**.

[0128] An autonomous toggling to the dynamically enhanced display may be actuated when a potential collision is present. This could be determined by various factors such as remote vehicles detected within a respective region proximate to the vehicle and an other imminent collision factor such as a turn signal being activated on the vehicle that indicates that vehicle is being transitioned or intended to be transitioned into an adjacent lane with the detected remote vehicle. Another example would be a lane detection warning system that detects a perceived unwanted lane change (i.e., detecting a lane change based on detection lane boundaries and while no turn signal activated). Given those scenarios, the rearview mirror display will automatically switch to the dynamically enhanced image. It should be understood that the above scenarios only a few of the examples that are used for autonomous enablement of the dynamically enhanced image, and that other factors may be used for switching the to the dynamically enhanced image. Alternatively, if a potential collision is not detected, the rearview image display will maintain the reflective display.

[0129] If more than one indicator and/or output display devices are used in the vehicle to display the dynamically enhanced image, then a display closest to what the driver is currently focusing on can be used to attract the driver's attention to notify the driver if a probability of a driver is likely. Such systems that can be used in cooperation with the embodiments described herein include a Driver Gaze Detection System described in copending application ______ filed ______ and Eyes-Off-The Road Classification with Glasses Classifier ______ filed ______, incorporated herein by reference in its entirety. Such detections devices/systems is shown generally at **218**.

[0130] FIG. **28** illustrates a flowchart for determining a fused time to collision. Similar reference numbers will be utilized throughout for already introduced devices and systems. Blocks **220**-**226** represent various time-to-collision techniques utilizing data obtained by various sensing devices that include, but are not limited to, radar systems, Lidar systems, imaging systems, and V2V communication systems. As a result, in block **220**, a time to collision is determined using data obtained by the imaging system. In block **222**, time to collision is determined using data obtained by radar sensing systems. In block **224**, time to collision is determined using data obtained by Lidar sensing systems. In block **226**, a time to collision is determined using data obtained by V2V communication systems. Such data from V2V communication systems include velocity, heading, and velocity, and acceleration data obtained from remote vehicles where a time to collision can be determined.

[0131] In block **228**, a time to collision fusion technique is applied to the results of each of the time to collision data output in blocks **220**-**226**. Time to collision fusion allows the time to collision from each output of the various systems to be cooperatively combined for providing enhanced confidence for a time to collision determination in comparison to just a single system determination. Each time to collision output from the each device or system for a respective object may be weighted in the fusion determination. Although the sensing and image capture devices are used to determine a more precise location of the object, each time-to-collision determined for each sensing and imaging device can be used to determine a comprehensive time-to-collision that can provide greater confidence than a single calculation. Each of the respective time-to-collisions of an object for each sensing device can be given a respective weight for determining how much each respective time-to-collision determination should be relied on in determining the comprehensive time-to-collision.

[0132] The number of time to collision inputs available will determine how each input will be fused. If there is only a single time to collision input, then the resulting time to collision will be the same as the input time to collision. If more than one time to collision input is provided, then the output will be a fused result of the input time to collision data. As described earlier, the fusion output is a weighted sum of each of the time to collision inputs. The following equation represents the fused and weighted sum of each of the time to collision inputs:

$$\Delta t_{TTC}{}^{out} = w_{im1}\cdot\Delta t_{TTC}{}^{im1} + w_{im2}\cdot\Delta t_{TTC}{}^{im2} + w_{sens}\cdot\Delta t_{TTC}{}^{sens} + w_{v2v}\cdot\Delta t_{TTC}{}^{sv2v}$$

where Δt is a determined time-to-collision, w is a weight, and im1, im2, sens, and v2v represent which image device and sensing device the data is obtained from for determining the time-to-collision. The weights can be either predefined from training, learning or can be dynamically adjusted.

[0133] In block **230**, the object detection results from the sensor fusion technique are identified in the image and highlighted with an object image overlay.

[0134] In block **120**, the highlighted object image overlay are displayed on the dynamic rearview mirror display.

[0135] While certain embodiments of the present invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.

What is claimed is:

1. A method of displaying a captured image on a display device of a driven vehicle comprising the steps of:

capturing a scene exterior of the driven vehicle by an at least one vision-based imaging device mounted on the driven vehicle;

detecting objects in the captured image;

determining a time-to-collision for each object detected in the captured image;

sensing objects in a vicinity of the driven vehicle by sensing devices;

determining a time-to-collision for each respective object sensed by the sensing devices;

determining a comprehensive time-to-collision for each object, the comprehensive time-to-collision for each object determined as a function of each of the time-to-collisions determined for each object;

generating an image of the captured scene by a processor, the image being dynamically expanded to include sensed objects in the image;

highlighting sensed objects in the dynamically expanded image that potential collisions to the driven vehicle, the highlighted objects identifying objects proximate to the driven vehicle that are potential collisions to the driven vehicle;

displaying the dynamically expanded image with highlighted objects and associated comprehensive collective time-to-collisions for each highlighted object in the display device that is determined.

2. The method of claim **1** further comprising the steps of:

communicating with a remote vehicle using vehicle-to-vehicle communications to obtain remote vehicle data for determining a time-to-collision with the remote vehicle, wherein the determined time-to-collision based on the vehicle-to-vehicle communication data is used to determine the comprehensive time-to-collision.

3. The method of claim **2** wherein determining a comprehensive time-to-collision for each object includes weighting each respective determined time-to-collision for each object.

4. The method of claim **3** wherein the determination of the comprehensive time-to-collision uses the following formula:

$$\Delta t_{TTC}{}^{out} = w_{im1}\cdot\Delta t_{TTC}{}^{im1} + w_{im2}\cdot\Delta t_{TTC}{}^{im2} + w_{sens}\cdot\Delta t_{TTC}{}^{sens} + w_{v2v}\cdot\Delta t_{TTC}{}^{sv2v}$$

where Δt is a determined time-to-collision, w is a weight factor, and

im1, im2, sens, and v2v represent each respective system that data is obtained for determining the time-to-collision.

5. The method of claim **4** wherein the weighting factors are predetermined weighting factors.

6. The method of claim **4** wherein the weighting factors are adjusted dynamically.

7. The method of claim **1** wherein the dynamically expanded image is displayed on an instrument panel display device.

8. The method of claim **1** wherein the dynamically expanded image is displayed on a center console display device.

9. The method of claim **1** wherein the dynamically expanded image is displayed on a rearview mirror display.

10. The method of claim **9** wherein the dynamically expanded image displayed on the rearview mirror is autonomously enabled in response to a detection of potential collision with a respective object.

11. The method of claim **10** wherein the potential collision is detected in response to a detection of the object and a detection of a lane change.

12. The method of claim **11** wherein the potential collision is detected in response to a detection of the object and an actuation of a turn signal indicating a lane change to a respective lane that the object is disposed.

13. The method of claim **11** wherein a collision warning symbol is displayed in the dynamic expanded image display providing a redundant warning to a driver for the highlighted object detected by a lane change assist system.

14. The method of claim **11** wherein a collision warning symbol is displayed in the dynamic expanded image display providing a redundant warning to a driver for the highlighted object detected by a lane departure warning system.

15. The method of claim **9** wherein the dynamically expanded image is disabled in response to not detecting potential collisions with objects, wherein the rearview mirror display device exhibits mirror reflective properties when the dynamic expanded image display is disabled.

16. The method of claim **9** wherein enabling and disabling the dynamically expanded image is actuated using a manual switch.

17. The method of claim **16** wherein the manual switch is disposed on the steering wheel for enabling and disabling the dynamically expanded image.

18. The method of claim **16** wherein the manual switch is disposed on the rearview mirror display for enabling and disabling the dynamically expanded image.

19. A method of displaying a captured image on a display device of a driven vehicle comprising the steps of:

capturing a scene exterior of the driven vehicle by an at least one vision-based imaging device mounted on the driven vehicle;

detecting objects in the captured image;

sensing objects in a vicinity of the driven vehicle by sensing devices;

generating an image of the captured scene by a processor, the image being dynamically expanded to include sensed objects in the image;

highlighting sensed objects in the dynamically expanded image that are potential collisions to the driven vehicle;

displaying the dynamically expanded image with highlighted objects on the rearview mirror, wherein the rearview mirror is switchable between displaying the dynamically expanded image and displaying mirror reflective properties.

20. The method of claim **19** wherein the dynamically expanded image displayed on the rearview mirror is autonomously enabled in response to a detection of potential collision with a respective object.

21. The method of claim **20** wherein the potential collision is detected in response to a detection of the object and a detection of a lane change.

22. The method of claim **21** wherein the potential collision is detected in response to a detection of the object and an actuation of a turn signal indicating a lane change to a respective lane that the object is disposed.

23. The method of claim **21** wherein a collision warning symbol is displayed in the dynamic expanded image display providing a redundant warning to a driver for the highlighted object detected by a lane change assist system.

24. The method of claim **21** wherein a collision warning symbol is displayed in the dynamic expanded image display providing a redundant warning to a driver for the highlighted object detected by a lane departure warning system.

25. The method of claim **19** wherein the dynamically expanded image is disabled in response to not detecting potential collisions with objects, wherein the rearview mirror display device exhibits mirror reflective properties when the dynamic expanded image display is disabled.

26. The method of claim **19** wherein enabling and disabling the dynamically expanded image is actuated using a manual switch.

27. The method of claim **26** wherein the manual switch is disposed on the steering wheel for enabling and disabling the dynamically expanded image.

28. The method of claim **26** wherein the manual switch is disposed on the rearview mirror display for enabling and disabling the dynamically expanded image.

29. The method of claim **19** further comprising the steps of:

determining a time-to-collision for each respective object detected by the at least one vision-based imaging device and the sensing devices

determining a comprehensive time-to-collision for each object, the comprehensive time-to-collision for each object determined as a function of each of the time-to-collisions determined for each object

displaying the comprehensive time-to-collision associated with each highlighted object on the rearview mirror.

30. The method of claim **29** wherein the driven vehicle communicates with a remote vehicle using vehicle-to-vehicle communications to obtain remote vehicle data for determining a time-to-collision with the remote vehicle, wherein the determined time-to-collision based on the vehicle-to-vehicle communication data is used in determining the comprehensive time-to-collision.

31. The method of claim **30** wherein determining a comprehensive time-to-collision for each object includes weighting each respective determined time-to-collision for each object.

32. The method of claim **31** wherein the determination of the comprehensive time-to-collision uses the following formula:

$$\Delta t_{TTC}^{out}=w_{im1}\cdot\Delta t_{TTC}^{im1}+w_{im2}\cdot\Delta t_{TTC}^{im2}+w_{sens}\cdot\Delta t_{TTC}^{sens}+w_{v2v}\cdot\Delta t_{TTC}^{sv2v}$$

where Δt is a determined time-to-collision, w is a weight factor, and

im1, im2, sens, and v2v represent each respective system that data is obtained for determining the time-to-collision.

33. The method of claim **32** wherein the weighting factors are predetermined weighting factors.

34. The method of claim **32** wherein the weighting factors are adjusted dynamically.

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