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A Surround View Image Generation Method with Low Distortion for Vehicle Camera Systems Using a Composite Projection

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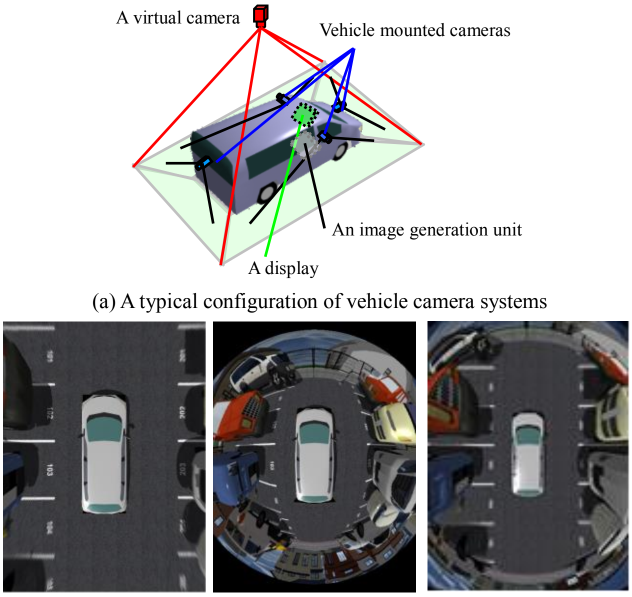
Abstract

This paper proposes a surround view image generation method for vehicle camera systems. To assist the driver during parking, a view with easy comprehension of distance and direction between the vehicle and objects is desirable. However, the conventional method of using an equidistant projection for generating a surround image of wide field of view causes image distortion, with straight lines appearing curved. This prevents the driver from correctly understanding the distance and direction of objects. Our proposed method uses a composite projection that combines two projection models: perspective projection and equidistant projection. This strategy can generate an image without distortion by using perspective projection near the vehicle and provides a wide field of view using equidistant projection. The experiments demonstrate the generation from parking scene images, using our proposed method, of a surround image with a wide field of view and no distortion near the vehicle.

1. Introduction

Vehicle camera systems have been proposed for assisting the driver's visual acuity for the purpose of preventing accidents and reducing the driver's workload [1]-[6]. Some have been commercialized. A typical example of a vehicle camera system for parking assistance, shown in Fig. 1a, takes images around the vehicle, eliminating blind spots using multiple vehicle-mounted cameras. It then generates a surround image, using an image generation unit, as would be seen from a virtual camera located above the vehicle, and shows it on a display in the vehicle. The driver can see objects hidden by the body of the vehicle, thereby reducing the risk of collisions with objects in blind spots.

As an image generation method for these systems, the use of a perspective projection camera model and plane shape model [4][5], and use of an equidistant projection camera model and a half ball shape model [6] have been proposed as image generation camera models and shape models around a vehicle. The image generated by the former method as shown in Figure 1b can display the image all around the vehicle, including blind spots for easy understanding of the vehicle and objects; but the narrow field of view cannot generally display views above a horizontal line. On the other hand, the image generated by the latter method as shown in Figure 1c can generate an image with a wide field of view. However,



(a) A typical configuration of vehicle camera systems

(b) Perspective projection on a plane (c)Equidistant projection on a half ball (d) Composite projection on a halfpipe **(proposed)**

Figure 1. A configuration of vehicle camera system and examples of generated surround view images.
(a) Generation of an image looking down the vehicle using 4 vehicle-mounted cameras, (b) perspective projection: the narrow field of view misses a pedestrian in the rear left, (c) equidistant projection: straight lines become curved in the image, (d) composite projection (as proposed) provides a wide field of view, including the pedestrian in the rear left, and maintains straight lines around the vehicle.

straight lines become curved in the image, and the distance on the image is not proportional to the actual distance between the vehicle and objects. As a result, the driver has difficulty in judging the distance and direction of objects around the vehicle.

For the purpose of generating a surround image, numerous methods have been proposed for achieving a wide field of view and no distortion of straight lines; but no methods have so far achieved both objectives. Other than the method of focusing on the three-dimensional shape of objects [1]-[2], the method of correcting image distortion [7][8] and the method of drawing guidelines [9] have been proposed, but no one has offered a fundamental solution.

This situation prompted us to propose a method of generating an image that simultaneously provides a wide field of view that includes objects above the horizontal line, as well as no distortion of straight lines near the vehicle, as shown in Figure 1d. As an image generation camera model, our method uses a composite projection that combines two projection models: perspective projection and equidistant projection. To generate an image near the vehicle, which is important for collision avoidance, perspective projection is used for generating an image without distortion. To generate an image far from the vehicle having a low possibility of collision, equidistant projection is used to generate an image with a wide field of view that can determine the presence of objects.

2. A surround view image generation method using a composite projection

2.1 Composite projection camera model

The relationship between the incident angle θ and image height r_c of a composite projection is shown in Eq.1.

Composite projection (Proposed)

$$r_c = \begin{cases} f_p tan\theta & if\ \theta \le \theta_c \\ f_e(\theta - \theta_c) + f_p tan\theta_c & otherwise \end{cases} \quad (1)$$

$$\theta = \mathrm{atan}(\frac{\sqrt{{x_e}^2 + {y_e}^2}}{z_e})$$

In this equation, f_p is the focal length of the perspective projection and f_e is that of the equidistant projection. θ_c is the incident angle at the boundary of the two projection models. f_p, f_e and θ_c can be independently set. In order to smoothly connect the image height r_c at θ_c, it is better to bring f_e close to $f_p/\cos^2\theta_c$.

Eq.1 describes a perspective projection when the incident angle θ is θ_c or below, and an equidistant projection when the incident angle θ is greater than θ_c.

When a virtual camera is placed in a position looking down at the vehicle from above, an image near the vehicle with an incident angle θ is θ_c or below is generated by perspective projection, and straight lines are shown as straight lines in the image. Images of areas far from the vehicle where the incident angle θ is θ_c or greater are generated by equidistant projection with a wide field of view that exceeds 180 degrees.

The threshold angle θ_c can be set according to the viewing angle that is desired to be perspective projection. For example, when the height of the virtual camera is 4[m], and the range of the perspective projection is within the radius of 6.7[m], $\theta_c=\tan^{-1}(6.7/4)=59$[deg.].

2.2 Generating the surround view image

Figure 2 gives an outline of how a surround image is generated. The following procedure is employed.

Step 1: Images around the vehicle are captured by cameras mounted on the front, back, left and right of the vehicle.

Step 2: The images from these vehicle-mounted cameras are projected onto a shape model that describes the three-dimensional shape around the vehicle.

Step 3: The image of the shape model is generated, as viewed from the virtual camera.

To generate an image viewed from the virtual camera, the pixel coordinates (u_c, v_c) of the vehicle camera that corresponds to the pixel coordinates (u_v, v_v) of the virtual

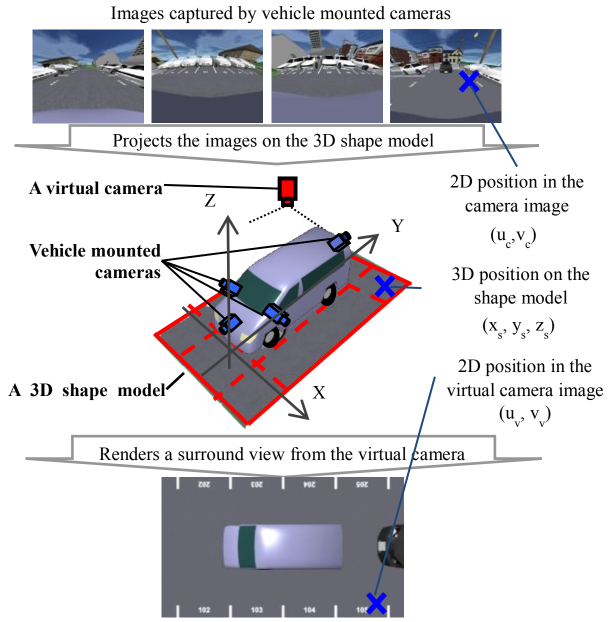
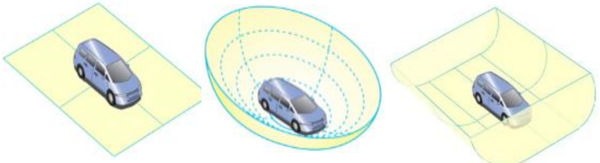


Figure 2. Process of generating a surround view.



(a) A plane (b) A half ball (c) A halfpipe

Figure 3. 3D shape models around the vehicle.

camera need to be obtained. By assuming that all pixel coordinates (u_c, v_c) of the vehicle camera exist on the points (x_s, y_s, z_s) on the shape model, the following Eq.2 can be obtained.

$$(u_v, x_v) = F_{vi}(x_{ve}, y_{ve}, z_{ve}) = F_{vi}(F_{vo}(x_s, y_s, z_s)) \quad (2)$$

$$(u_c, x_c) = F_{ci}(x_{ce}, y_{ce}, z_{ce}) = F_{ci}(F_{co}(x_s, y_s, z_s))$$

In this equation, F_{vi} and F_{vo} are the projection conversion and coordinate conversion of the virtual camera, and F_{ci} and F_{co} are the projection conversion and coordinate conversion of the vehicle camera. Also, (x_{ve}, y_{ve}, z_{ve}), (x_{ce}, y_{ce}, z_{ce}) are respectively the coordinate values of the virtual camera coordinate system and vehicle camera coordinate system. The camera parameters such as focal distance and vehicle-mounted positions need to be measured in advance. Since the composite projection model is a model of virtual camera, calibration of a composite projection camera is not necessary.

For the shape model around the vehicle, a plane shape model (Fig.3a), and a half-ball shape model (Fig.3b) used in [3]-[6] are used. In our proposed method, a half-pipe shape model (Fig.3c) is newly introduced.

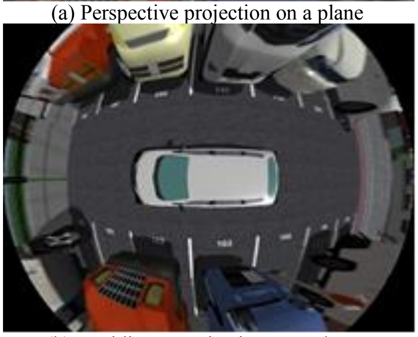
The image stitching method is not applied in this paper. In order to generate the image at the joint of two cameras, the images of the left and right cameras are preferentially used rather than the images of front and rear cameras.

3. Evaluation experiments

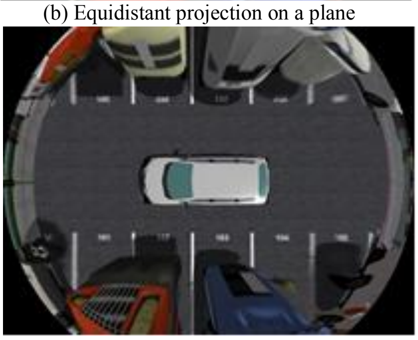
3.1. Comparative evaluation of camera models

A comparative evaluation was made with the surround

(a) Perspective projection on a plane



(b) Equidistant projection on a plane



(c) Composite projection (**proposed**) on a plane

Figure 4. Images generated by (a) perspective, (b) equidistant and (c) composite projection.

Table 1 Values of camera parameters

Camera model	Parameters and values used in the experiment
Perspective projection	Focal distance: fp=1.6[mm] Camera position: (x, y, z)=(0.0, 2.5, 4) [m]
Equidistant projection	Focal distance: fp=2.0[mm] Camera position: (x, y, z)=(0.0, 2.5, 4) [m]
Composite projection	Focal distance: fp=1.6[mm] Focal distance: fe=0.96[mm] Angle threshold value: θ=59 [degrees] Camera position: (x, y, z)=(0.0, 2.5, 4) [m]

image generated using a composite projection camera model and two other conventional camera models of perspective projection and equidistant projection. The relationship between incident angle θ and image height r_p and r_e is shown in Eq.3 and Eq.4.

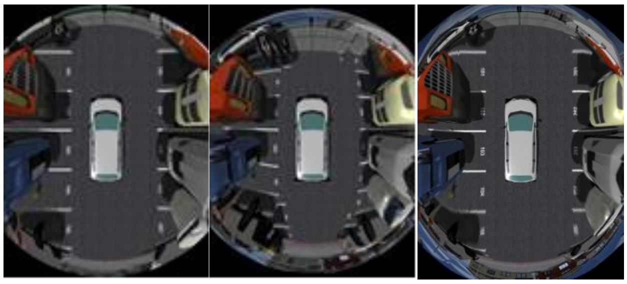
Perspective projection: $r_p = f_p tan\theta$ (3)

Equidistant projection: $r_e = f_e\theta$ (4)

In the above equation, f_p and f_e are respectively the focus distance in the perspective projection and equidistant projection.

In the experiment, the images of the four vehicle mounted cameras are generated by computer graphics. Camera mounting positions were determined as the front grille, under the left and right door mirrors and the rear license plate. The major parameters of the three camera models and the values used for the experiment are shown in Table 1. The shape model around the vehicle used for generation of a surround image was determined as a plane model in Fig.3a.

Figure 4 shows the surround images generated using



(a) Composite projection on a plane (b) Composite projection on a half ball (c) Composite projection on a halfpipe

Figure 5. Images generated using (a) a plane, (b) a half ball and (c) a halfpipe shape models.

Table 2 Values of shape models

Camera model	Parameters and values used in the experiment
Plane shape model	Plane position: z=0 [m]
Half-ball shape model	Horizontal direction radius: r_{xy}=10.0[m] Vertical direction radius r_z=3.0 [m]
Half-pipe shape model	Left-right direction width : w=16.0 [m] Front-back direction length: L=48.0 [m] Corner radius: r=2.0 [m]

perspective projection, equidistant projection and composite projection. Fig.4a, generated using a perspective projection camera model, shows the surround image near the vehicle with easily understandable positions of the vehicle and objects. However, it provides a narrow field of vision and does not allow to see far away. Fig.4b, generated using an equidistant camera model, provides a wide field of vision and allows to see far away. However, straight lines appear as curves. For this reason, the actual distance between the vehicle and object is not proportional to the distance on the image, making the distance between the vehicle and external objects difficult to judge. On the other hand, our proposed method, using the composite projection camera model shown in Fig.4c, also shows straight lines as straight in the image of items near the vehicle, and therefore, the distances between the vehicle and objects and their direction are easy to understand.

Full surround images generated using the three shape models are shown in Figure 5. The image generated using the plane shape model (Fig. 5a) only provides a field of view under the horizontal line.

The image generated by using the half-ball shape model (Fig.5b) shows straight lines as curved, making the direction and distance between the vehicle and objects difficult to understand. In contrast, the image generated using the half-pipe shape model (Fig.5c) includes a field of view above the horizontal line. The straight line on the image near the vehicle also provides easy understanding of the direction as well as the distance between the vehicle and objects. Based on the observation as described, a combination of the composite projection camera model and half-pipe shape model was confirmed to generate a surround image with a wide field of view without any bending of straight lines near the vehicle.

3.2. Evaluation by using actual image of parking scene

To evaluate the effects of generating a surround image with a wide field of view and distortion-free straight lines using the proposed method, an image was generated by simulation by using an actual image of a parking scene. As comparison targets, the two following conventional methods were used.

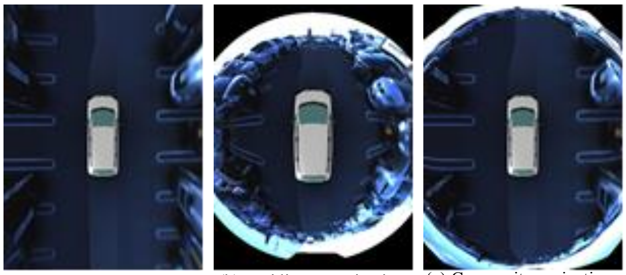
Proposed method: Composite projection model and half-pipe shape model

Conventional method 1: Perspective projection model and plane shape model [4][5]

Conventional method 2: Equidistant projection model and half-ball shape method [6]

Surround images of a parking scene generated using the proposed method and conventional methods 1 and 2 are shown in Figure 6. The image generated by the proposed method (Fig.6c) provides a wider field of view than the image (Fig.6a) generated by conventional method 1, and lower distortion near the vehicle than the image (Fig.6b) with straight lines near the vehicle, also shown as straight lines, in the image permitting easy judgment of the direction as well as distance between the vehicle and objects.

Shown in Figure 7 is the example surround images generated by the proposed method. The figures show that the proposed method can generate images with a wide field of view while maintaining straight lines in a variety of parking scenes.



(a)Perspective projection on a plane (b)Equidistant projection on a half ball (c) Composite projection on a halfpipe (proposed)

Figure 6. Generated images of parking scenes.

Figure 7. Generated images in various parking sites (proposed method).

4. Conclusion

This paper proposes a method of generating surround images using a composite projection model that combines perspective projection and equidistant projection as an image generation camera model. This method can generate images without distortion near the vehicle by using perspective projection and a wide field of view that allows distances to be understood, by using equidistant projection.

The experiment, employing a variety of parking scenes taken using an experimental vehicle, demonstrated that our proposed method can produce images that include horizontal lines in the surrounding area, with straight lines near the vehicle shown as straight lines on the image, and with minimal distortion when indicating the distance between the vehicle and objects as proportional to that on the image. This method thus has been shown to generate images with a wide field of view and easy-to-understand direction and distance information between the vehicle and nearby objects.

It is know that drivers gaze around the parking space and obstacles and also gaze at the far side of the road during parking [10]. Since drivers can see these gaze points from the generated images at the same time, our proposed method is effective for parking assistance.

We believe our proposed method to be effective not only for assisting the driver during parking, but also for backing up and driving along narrow roads with sharp left and right turns. We plan to verify the effectiveness of this method for driver assistance other than for parking.

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