Development of Image Synthesis Algorithm with Multi-Camera

Kapje Sung, Joongryoul Lee, Junsik An, and Eugene Chang
Hyundai Motor Company, Rep. of Korea
e-mail: kjsung@hyundai.com

Abstract— **AVM system is recently being adopted to the automotive industries to show area around the vehicle. This system combines images from four cameras and provides the driver with a synthesized image. This study proposes a camera parameter optimization algorithm to establish highly accurate image of the surrounding using the correspondence between the overlapping cameras. And we propose a mathematical multi-camera model to design projection models. As a result, by using these models, we can design various view modes.**

Keywords-Image Synthesis, AVM, Around View Monitor, Top View, Bird's-eye View, Projection Model.

I. INTRODUCTION

Recently the ratio of installation of automotive camera has shown rapid increase. Cameras installed only in luxury cars previously are now being installed in lower grade cars. US pushes ahead with acts to strengthen the regulation on the field of rear vision, that the rear view camera should be surely installed at all cars sold from 2014.

Automotive camera system is largely divided into two types according to the method of using camera image. First there is camera system used for controlling vehicle or notifying situation to driver through image recognition. Camera of lane departure warning system(LDWS), driver status monitoring (DSM) system, or approaching obstacle warning system (AOWS) and so on belongs to this type. And the other is the camera system to show drivers situation around vehicle by plain camera image or reconstructing it. Front or rear view camera system, AVM(Around View Monitor) system[1][2] and so on belongs to the second type.

AVM system has recently appeared among systems directly showing driver camera image, but has a tendency to expand application rapidly. Many automotive OEMs have already carried out mass production of the system, and are gradually increasing the types of car that it is installed. One of important elements to influence performance of AVM is image alignment on boundaries that four images are reconstructed.

In this paper, we suggest multi-camera image reconstruction algorithm and view model that we developed. It was shown that various projection models could be made, and image alignment on boundaries could be improved through our algorithm based on camera model. And various view modes of AVM implemented through the developed algorithm were introduced, and the performance of the developed algorithm was shown.

II. DEVELOPMENT OF MATHEMATICAL MODEL FOR MULTI-CAMERA IMAGE RECONSTRUCTION

A. Around View Monitor

AVM is the system to show driver the situation around vehicle by reconstructing multi-camera images into a single image that looks to be filmed by one camera, as shown in Fig. 1(c). It is made possible for the driver to judge the relation between the vehicle and its surrounding obstacles, and relation between the vehicle and parking lot line in case of parking, because the driver can recognize situation around vehicle at a glance.

(a) original (b) transformed (c) AVM

Figure 1. Around View Monitor(AVM)

Fig.1 shows the process of AVM image reconstruction. First each original image like Fig.1 (a) is obtained from the cameras installed at front bumper, rear bumper, and outside rear view mirrors. Next, each original image is transformed as in Fig.1 (b). Lastly, each transformed images are reconstructed into the final image like Fig.1 (c).

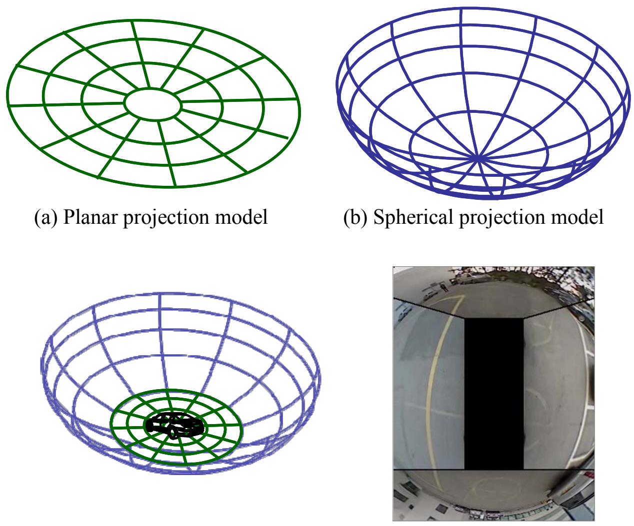
Above all, camera parameters of four cameras should be extracted for the image transformation which is the second process. The camera parameters are extracted using the relation between the world coordinate and the image coordinates. If this relation is known, images can be transformed from distorted original image into the type of view that designer wants can be acquired.

Because the concept of virtual camera is used in case of reconstructing four images, reconstructed image with the position and angle that user wants can be obtained from real camera image. Field that image is visible is differently shown according to the original image. For example, if a virtual camera looks down a vehicle from the sky like Fig. 1(c), the result of the front camera image transformation only show the front part of vehicle, and result of the right camera image transformation only show the right part of vehicle. If each visible field is cut and reconstructed like this, final AVM reconstruction result image can be obtained.

B. Development of projection model and its hybrid

The process to transform 2D image coordinates into 3D world coordinates is required for view transformation by using virtual camera. At this time, because one dimension is added, one dimension should be assumed in order to obtain world coordinates.

Because the surroundings of vehicle are generally ground in many cases, Z=0 may be assumed in world coordinates. That is, view transformation is carried out by assuming that all visible fields in the image are on the ground. It is called planar projection model. This model can satisfy image alignment of reconstruction boundaries. But it has weak point that the field near to vehicle can only be shown.



(a) Planar projection model (b) Spherical projection model

(c) Hybrid projection model (planar+spherical model) (d) AVM result (with hybrid model)

Figure 2. Projection model

Spherical projection model has a spherical shaped projection surface with the vehicle as the center like Fig.2 (b). If 2D image coordinates are transformed into 3D world coordinates, these are placed on spherical surface. Spherical projection model has advantage that can show both near place and field far from the vehicle at a time, but has a disadvantage that image alignment on reconstruction boundaries is inferior.

We developed hybrid projection model like Fig.2 (c) by combining only advantages of these two projection models. It is a hybrid projection model that planar projection model is used for the field near to vehicle, and spherical projection model is used for the field far from vehicle. By using this model, image alignment of field near to vehicle is satisfied, and simultaneously the field far from the vehicle can be seen at a glance.

Fig.2 (d) is an example of AVM view mode by using hybrid projection model. Considering reconstruction boundaries, it is shown that a traffic lane near to vehicle is naturally aligned. Obstacles approaching the vehicle can be grasped, for the field far from the vehicle can also be seen at a glance at the same time.

Here, projection model can be made according to the intention of designer by freely adjusting variables, such as distance to boundaries of planar model and spherical model, radius of sphere and so on.

This hybrid projection model (planar projection model + spherical projection model) is an example, and new and various projection models can be additionally made without limit, if our algorithm based on camera model is used. For example, model combining planar model and cylindrical model can be made, and model combining two planar models can also be made.

C. Development of camera parameter optimization algorithm

Camera parameters are composed of intrinsic parameters and extrinsic parameters. Intrinsic parameters can be expressed by lens focal length, image sensor parameters, and distortion parameters. Extrinsic parameters are the model to express the geometrical installation status of camera, and can be expressed by rotation parameters and translation parameters.

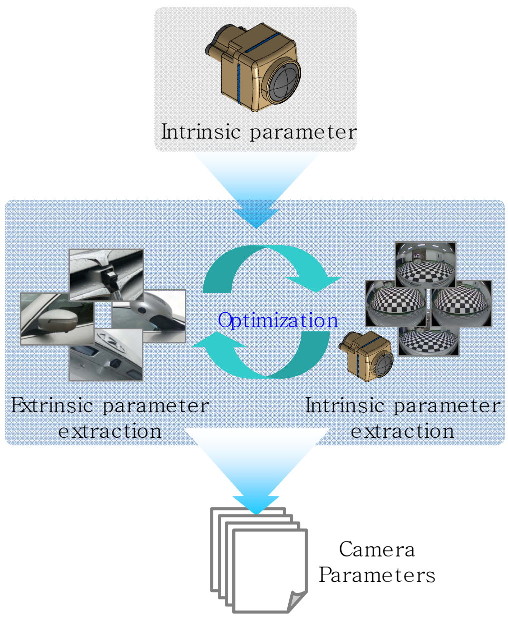
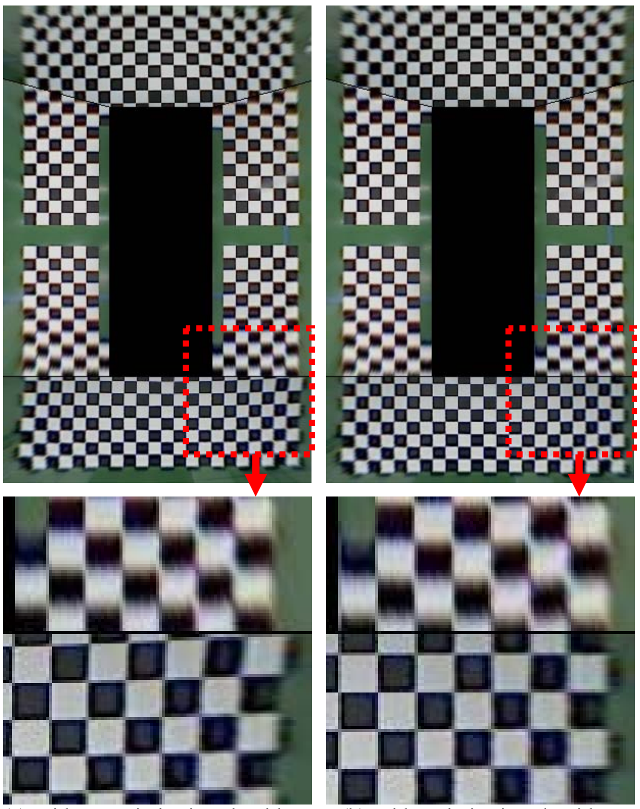


Figure 3. Camera parameter optimization algorithm

Ideally, the same kind of camera should have the same intrinsic parameters. But every camera unit has a little different intrinsic parameters due to error in optical axis and focal length and so on, which occurs during the manufacturing process of camera. Because alignment on AVM boundaries is sensitive to optical characteristics of the camera, intrinsic parameter error occurring between each camera unit lowers the alignment on boundaries. In order to satisfy image alignment, intrinsic parameters should be calibrated for all cameras installed at vehicle, which is very hard in mass production system.

We developed camera parameter optimization algorithm in order to solve this problem. This algorithm acquires extrinsic parameters, and simultaneously calibrates intrinsic parameters, as a result, improves alignment on boundaries of AVM. Camera parameter optimization algorithm is largely divided into a stage to extract extrinsic parameters, and a stage to extract intrinsic parameters like Fig.3, and error is reduced by repeatedly carrying out these two stages.

This algorithm requires intrinsic parameters as initial value. Because four cameras are generally the same kind, the initial values of intrinsic parameters need only to be calculated for a camera in advance. Then, each extrinsic parameters of the four cameras are extracted on the basis of the initial values[3]. Now, intrinsic parameters are again extracted by using the extrinsic parameters as initial value. If stage to extract the intrinsic parameters and stage to extract the extrinsic parameters are repeated like this, pixel error is gradually decreased. Final values are calculated by repeating the process, until decrease of pixel error is under a certain level.



(a) Without optimization algorithm (b) With optimization algorithm

Figure 4. Result of camera parameter optimization algorithm

Fig.4 compares the reconstruction result that optimization algorithm is not applied, with the case that it is applied. It is shown that the alignment on boundaries is inferior, if the algorithm is not applied. In addition, it is shown that the part that should be a straight line is severely bent outward on boundaries of the right side and rear side. On the contrary, it is confirmed that bending phenomenon disappears and alignment is improved in the reconstruction results that the optimization algorithm is applied to.

D. Development of algorithm for auto calibration

Ideally, because camera type is the same, and camera installation position and angle is the same in case of the same type of vehicle, the alignment on boundaries of AVM reconstruction image should be well carried out, if camera parameter extracted once before is used. But even the same type of vehicle has different alignment on boundaries realistically. The reason is that error of intrinsic parameters does not only occur between camera units as mentioned in section II-C, but also assembly tolerance occurs in case of installing camera at vehicle assembly line. Therefore, intrinsic parameters and extrinsic parameters of each manufactured vehicle are required to be calibrated, if alignment of boundaries is intended to be satisfied.

Camera parameter calibration of each vehicle is carried out at the last stage of assembly line. After vehicle is lined up in the space that certain pattern is arranged, image of pattern is obtained from each camera, and camera parameter calibration is carried out on the basis of this.

Auto calibration algorithm automatically detects feature points by using Harris corner detection algorithm[6], and accurate intrinsic and extrinsic parameters are calculated by using camera parameter optimization algorithm introduced in section II-C on the basis of this.

III. DEVELOPMENT OF VIEW MODES BASED ON PROJECTION MODEL

The alignment on boundaries is important in AVM, but it is also considerably important how to reconstruct four camera images and to show these to driver. A new view mode can be developed without limit, if concept of previously explained projection model is used. The optimum view mode fit for driving and parking situation can be developed by setting up position, angle, and projection model of the virtual camera. Fig.6 shows example of view modes that we developed.

Short-range top view of Fig.5 is the basic view mode, which is used most. This view mode much helps grasping relation between the vehicle and the surroundings during parking by showing the field near to the vehicle in detail.

Long-range top view of Fig.5(b) has the same viewpoint of virtual camera of Top view(near), but makes it possible to see even the field far from the vehicle by using hybrid projection model of section II-B. This view mode can be used for grasping situation around vehicle, and existence of approaching obstacle just before the start of parking.

(a) Short-range top view (c) Rear-side view

(b) Long-range top view (d) Bird's-eye view

Figure 5. View modes

Rear-side view of Fig.5(c) makes it possible to observe situation near the rear wheel by reconstructing rear view camera image with the left and the right side camera image. This view mode makes it possible to grasp distance between tires and curbs as well as rear side of the vehicle in case of backing, when parallel parking is carried out.

Because bird's-eye view of Fig.5(d) has a view that virtual camera observes vehicle from rear-above side of the vehicle, it can be used for observing the right and left side during the vehicle movement.

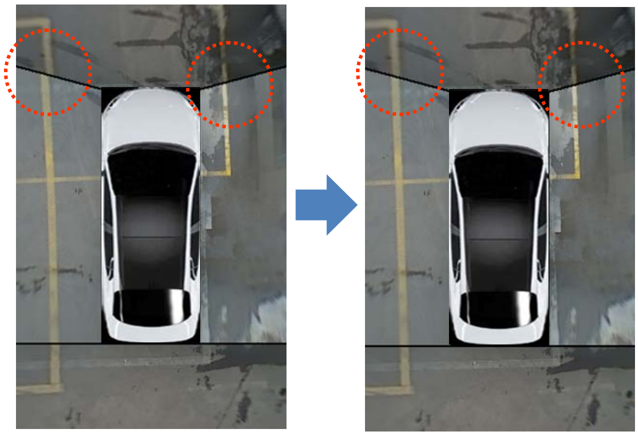
IV. RESULTS

We can see the calibration results in Table.1. Average of calibration error is 1.37 when the optimization algorithm is not applied. But the error is reduced to 0.3 if the optimization algorithm is applied.

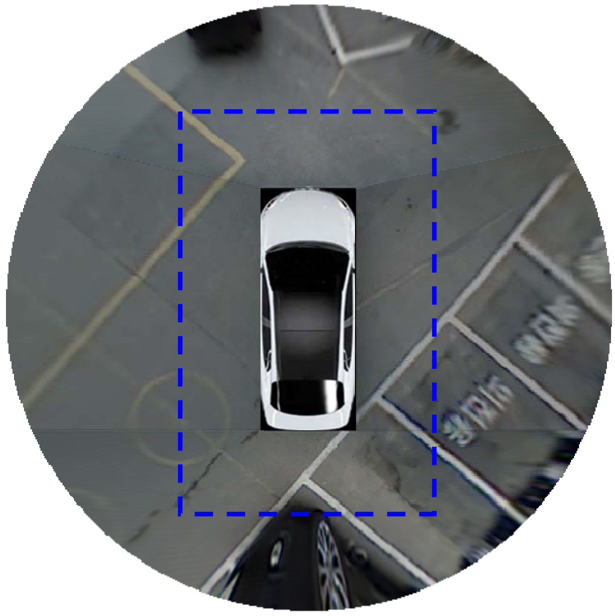
Fig.6 shows reconstruction results with real data in parking situation. Fig.6(a) is the reconstruction results that optimization algorithm is not applied. It is shown that alignment of lane around vehicle is inferior, if the algorithm is not applied. On the contrary, the optimization algorithm improves alignment

TABLE I. CALIBRATION ERROR COMPARISON

Optimization algorithm	Calibration Error [pixel]				
	Front	Rear	Left	Right	Average
Not applied	1.54	1.47	1.31	1.17	1.37
Applied	0.34	0.33	0.26	0.27	0.30



(a) With optimization algorithm (b) Without optimization algorithm



(c) With optimization algorithm(wide range)

Figure 6. Results in parking situation

like Fig.6(b). Fig.6(c) shows reconstruction result with wide range. We can see up to 6m from vehicle. The more distance from vehicle is long, the more difficult we make a good alignment on boundaries. But the lane is naturally expressed in the field far from the vehicle.

V. CONCLUSION AND FUTURE PLAN

A. Conclusion

We obtained results showing the improvement of the performance of AVM system, and to increase design degree of freedom, by developing mathematical model and algorithm for multi-camera image reconstruction. Projection model and view mode of AVM was made to be capable of being designed freely, by developing mathematical model of multi camera, and alignment on boundaries of AVM was improved through camera parameter optimization algorithm. Conclusions as follows were obtained through this.

(1) Multi camera image reconstruction technology that we developed can design various projection models by using mathematical model of camera.

(2) Design degree of freedom in AVM view mode can be obtained through modifying position and angle of virtual camera.

(3) Necessary view mode according to situations during parking process, such as short-range top view, long-range top view, rear-side view, and bird's-eye view and so on was developed through algorithm that we developed.

(4) Accurate intrinsic and extrinsic parameter can be extracted through camera parameter optimization algorithm, and consequently alignment on boundaries of AVM can be improved.

B. Future plan

Dedicated chips for image processing appear according to recently developing semiconductor technology. It is planned that next generation AVM system is developed as ECU, by applying the developed algorithm to this. It is intended that new view mode and new contents are developed for improving salability of AVM through the process. Furthermore, it is planned that integrated parking assistance system is developed by combining with other parking assistance systems such as SPAS(Smart parking assist system), BSD(Blind spot detection), and AOWS(approaching obstacle warning system) and so on.

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