Wraparound View System for Motor Vehicles

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The use of vehicle-mounted cameras, including one for the rearview monitor, has become increasingly popular recently. These cameras can help make driving easier and safer by reducing the number of blind spots around the vehicle. We have now developed a new wraparound view monitoring system that combines video images from four cameras and provides the driver with a full field of vision around the vehicle with no blind spots. This technology is built into a vehicle-mounted system, which consists of an MB86R01 System-on-a-Chip (SoC) graphics controller for automobiles supplied by Fujitsu Microelectronics Ltd. and a video processing chip FPGA that synchronizes the images from the four cameras and conducts multiplex synthesizing on those video images. The system is capable of processing the input video images at a rate of up to 30 ms per frame and showing the processed images to the driver. This technology thus can offer proper visual assistance to the driver in a variety of driving conditions, including when parking the vehicle, passing oncoming traffic on a narrow street, entering an intersection with poor visibility, and turning left or right. This paper describes our new wraparound view monitoring technology and its application to a vehicle-mounted system.

1. Introduction

When driving current vehicles the driver has many blind spots. Drivers try to ensure safety not only by directly observing their surroundings, but also by using such visual assistance as rearview mirrors inside the vehicle and on the left and right doors or fenders. These means alone, however, are not sufficient for large vehicles or for a driver with poor physical capabilities to sufficiently ensure safety. Hence, there has been increasing demand for vehicle-mounted cameras. In Japan the demand for such cameras is mainly for rearview monitors and, in 2007, more than four million vehicle-mounted cameras were sold.[1)] Sales of such cameras in markets outside Japan are also expanding rapidly, and are expected to overtake sales in Japan in 2010 and reach about 13.8 million sets in 2012, far exceeding the estimated sales of 4.8 million sets in Japan in the same year.[2)] Demand for such cameras will likely increase rapidly in the United States where the Cameron Gulbransen Kids and Cars Safety Act of 2007, which is intended to ensure, among other things, rearward visibility for drivers, was approved in February 2008. One of the objectives of this bill is to prevent children from being run over by reversing vehicles. Rearview monitors are reported to be effective in ensuring the driver has rearward visibility and thus vehicle-mounted cameras are expected to become even more popular in the United States.

Some vehicle-mounted camera systems that serve as a visual assistance for drivers, each using a single camera, are already commercially available. They include a rearview monitor, a blind corner monitor that gives the driver views of blind spots at intersections with poor visibility, and a side view monitor that minimizes the blind spot when passing oncoming traffic. Another type of conventional visual assistance is a bird's-eye view camera system[3] that synthesizes video images from four cameras mounted around the vehicle and provides the driver with an overhead view of the vehicle and the area around it. These systems, however, are single-function systems and thus the driver needs to switch from one system to another depending on the driving conditions.

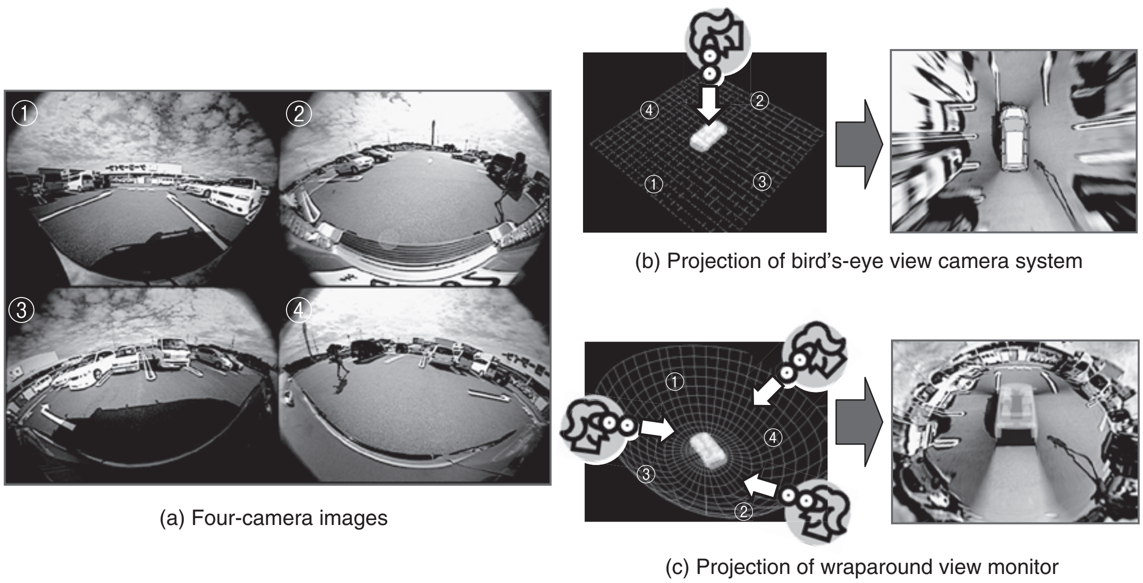
In order to further improve driver visibility, we have developed a wraparound view monitor that enables the driver to see optimum field-of-view images for a variety of vehicle operating conditions, and we successfully built a prototype vehicle-mounted system that functions on a real-time basis.

This paper first deals with conventional bird's-eye view camera systems and summarizes the problems with the current driver visual assistance technology, and then goes on to explain the basic principles of the newly developed technology, its application to vehicle-mounted systems, actual situations where our system can be used, and possible problems with it. This paper summarizes future prospects for the application of this technology as well.

2. Bird's-eye view camera system

A bird's-eye view camera system converts video images recorded by four cameras, which are mounted in the front, rear, and on the left and right sides of the vehicle, into a bird's-eye view image and shows the driver images which have been synthesized on a screen [**Figure 1 (a), (b)**]. Conversion of the images into a bird's-eye view can be achieved via projection conversion which in turn uses a homography matrix,[4] or by making image projection processing in a 3-D space.[5] In the latter case, the images are projected onto a flat surface equivalent to the road surface. In both conversion methods, the bird's-eye view camera system requires a flat surface on which to project the images.

Although this system is effective for visualizing objects around the vehicle, it has a drawback in that since the images are projected on a flat surface, the shapes of objects far away



(a) Four-camera images

(b) Projection of bird's-eye view camera system

(c) Projection of wraparound view monitor

Figure 1
Overview of two image projection technologies.

from the vehicle tend to be blurred. This occurs because the area covered by one camera image sensor becomes wider as the distance from the vehicle increases [**Figure 2 (a)**]. In addition, the point of view is fixed right above the vehicle, and hence only a relatively small area, extending 2 to 3 meters directly around the vehicle, can be shown. Because of this narrow field of view, this system alone is not capable of displaying all the vehicle's surroundings, and thus different images from other monitors such as the rearview monitor must be shown simultaneously, or the driver must look directly outside the vehicle and at the rearview mirrors simultaneously.

3. Problems with visual assistance system

The following improvement must be made to realize a visual assistance that enables the driver to instantly confirm safety around his vehicle without any blind spots in a variety of driving conditions including parking, turning, and merging.

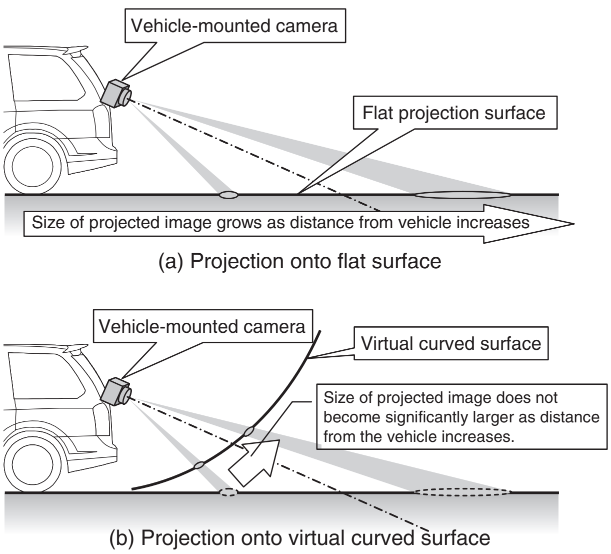


Figure 2
Principle of 3-D virtual projection/point of view conversion technology.

3.1 Relieving the driver from the need to look around the vehicle

To ensure vehicle safety, the driver has to quickly recognize multiple fields of view, using, in addition to his direct vision, the rearview mirrors in the vehicle and on the doors, as well as other visual assistance systems including the rearview monitor. This increases the burden on the driver. As stated earlier, the bird's-eye view camera system does not provide the driver with consolidated visual information, meaning that the driver still has to look around the vehicle.

3.2 Problem related to driver's recognition of images on the monitor as it relates to the point of view, direction of view, and field of view

With conventional technology, the monitor displays images taken from a different point of view and direction of view for each function and camera, quickly switching from one image to another. This makes it difficult for the driver to recognize instantly what he is looking at and from what point of view. And this makes it hard for the driver to ensure safety quickly, limits the application to only certain driving conditions, and requires a relatively long time for the driver to get used to the system.

4. Basic principles of wraparound view monitor

We have developed a wraparound view monitor, which represents a new driver's visual assistance device as video processing technology, in order to solve those problems. This system is capable of displaying a wraparound view of the vehicle from a selectable point of view and from a selectable line of sight, and allows a smooth transfer of line of sight when the images on the monitor are switched.

This system uses four cameras, one each in the front and rear and on the left and right sides of the vehicle. The video images from these cameras are projected onto a virtual 3-D curved surface, and the images on that surface are converted into those seen from any desired point of view using the technology of 3-D virtual projection and point of view conversion. Though the images taken by the four cameras are the same as those taken by a bird's-eye view camera, images from any desired point of view can be displayed after the point of view has been converted, and thus synthesized images are significantly different from those of the conventional systems [**Figure 1 (c)**]. In addition, since the images are projected onto a 3-D curved surface, the area covered by each camera image sensor does not become much larger even if the distance from the vehicle increases [**Figure 2 (b)**]. The images can be processed in such a way that the resolution of each image sensor is about the same, which will result in images being displayed with much less distortion, which in turn will make it easier for the driver to recognize obstacles around his vehicle.

Furthermore, our system uses point-of-view interpolation technology, which ensures a smooth shift of the driver's line of sight when he switches the display from one image to another. Since the position of the point of view, the direction of view, and the scope of field of view are interpolated before and after switching the point of view, the driver can instantly recognize at what position in the display he is watching his own vehicle, and quickly ensure safety.

5. Application to vehicle-mounted system

In order to verify the vehicle-mounted video technology for a driver's visual assistance as mentioned above and examine the performance of our wraparound view monitor, we mounted four cameras on a test vehicle and built a wraparound view monitoring system (**Figure 3**). This system uses a dashboard monitor to display video images processed from the images fed from four cameras. The four cameras are mounted on the front bumper, the lower faces of the left and right door mirrors, and on the tailgate door, respectively. Each of these cameras is a

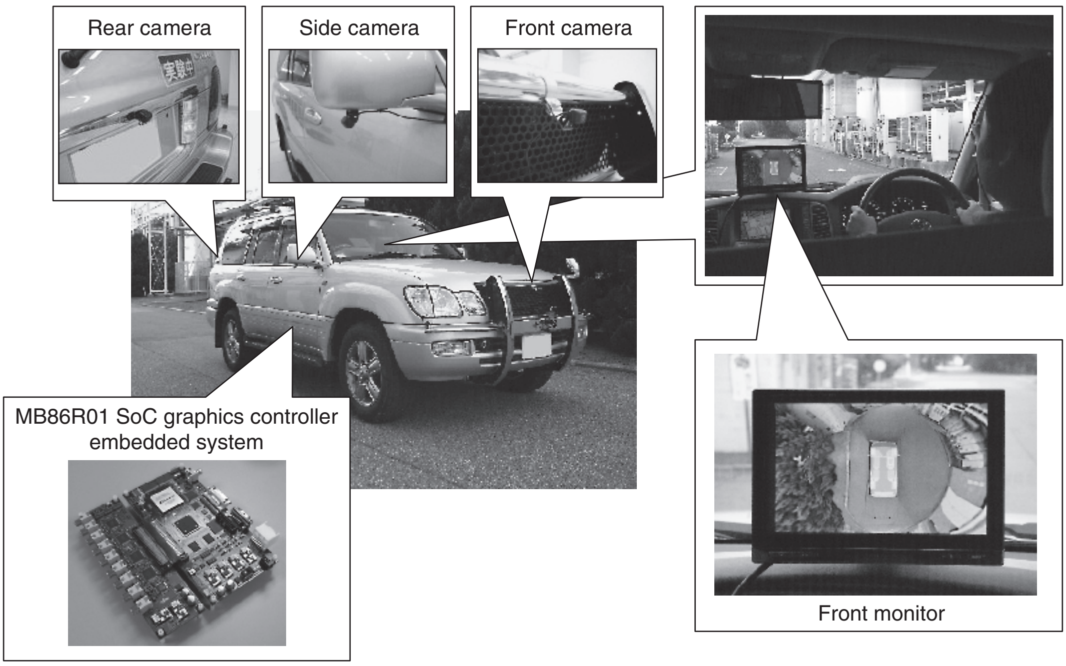


Figure 3
Test vehicle.

30-megapixel CMOS camera made by Fujitsu General Ltd., but other vehicle-mounted cameras for universal application can also be used. The camera's horizontal angle of view is 190 degrees. With four cameras, video images covering 360 degrees around the vehicle are taken on the basis of an analog NTSC system with some overlap between the recorded views.

The video images from the four cameras are multiplex-synthesized while being harmonized and then converted into wraparound images. This multiplex-synthesis processing is programmed into the FPGA. Synthesizing wraparound images from the multiplex images is done on an MB86R01 System-on-a-Chip (SoC),[6] which is a highly integrated device for embedded automobile graphics applications supplied by Fujitsu Microelectronics. The processor core for this SoC is ARM926EJ-S made by ARM Ltd. of the U.K., and the SoC has a graphics display controller (GDC), video processing circuit, memory circuit, and other components integrated on a single chip. MB86R01 converts the points of view of each camera, synthesizes the images from the cameras, and allows smooth scrolling of the displayed images. The time required to synthesize the images from the four cameras is only 30 ms, and thus a real-time performance is achieved.

As the 3-D rendering interface, MB86R01 uses a group of APIs based on the OpenGL ES1.1 Common profile and Common-Lite profile (fixed point) which are a general-purpose embeddable image processing platform. The wraparound view monitor was first constructed on a personal computer and then was ported to an embedded system. It was quite easy to port it to the embedded system because a 3-D rendering had been made using the same OpenGL APIs as the personal computer.

6. Study on system in actual use conditions

Now the system has been installed on a test vehicle it can be easily studied while in actual use. We conducted the study in two ways: we created wraparound view images off-line after recording video images during vehicle operation using four cameras, and we synthesized images in real time during vehicle operation, and then showed those images to the driver and other occupants on a monitor. The method to use will change depending on the potential risk involved.

6.1 Parking

The new system covers a wider area than the conventional rearview monitor, and is capable of recognizing obstacles farther away from the vehicle than the bird's-eye view camera system can. This function enables the driver to confirm a series of operations from the approach to, and the completion of parking in, a parking space from a single point of view. Since many other vehicles and even pedestrians have access to a parking lot, the capability of the system to let the driver view and confirm a field of view even if that field is not directly related to the operation the driver is about to make, can give the driver a sense of assurance.

6.2 Passing on a narrow street

Since the tires and fenders are displayed on the monitor, the driver can bring his vehicle as close as possible to the curb when passing on-coming traffic on a narrow street. The field of view monitored is not limited to the vicinity of the tires as with the conventional side view monitor. The driver can also view the direction in which he is going, as well as the conditions of the on-coming traffic.

6.3 Intersection with poor visibility

By widening the area covered by the front camera, and by synthesizing and displaying a wraparound view, our system enables the driver to view other vehicles approaching an intersection from the left and right. In addition, the system can display, from one point of view, views of both the left and right sides of the street as seen from the vehicle, enabling the driver to identify passing pedestrians and bicycles as well.

6.4 Pedestrian protection at intersection

When turning left at an intersection, the left side of the vehicle is displayed on the monitor, which ensures the safety of pedestrians [**Figure 4 (a)**]. Since both the side view and front view are displayed on the same screen, the driver can see what lies straight ahead even while he is looking left, which again gives him a sense of assurance.

6.5 Merging into a highway

The monitor displays the vehicle from a point of view in front of the vehicle, enabling the driver to see vehicles approaching from the rear on the highway, and at the same time see the highway lane into which he is merging [**Figure 4 (b)**]. The images from the point of view in front of the vehicle are shown mirror-reversed on the monitor as if they were seen in a rearview mirror, giving the driver instinctive spatial perception. This point of view is also useful when changing lanes. When merging into a highway and changing lanes, the driver must look at a relatively wide area, which is difficult for beginner drivers. With our system, an inexperienced driver can look at the roadway after confirming on the monitor where obstacles are around his vehicle, and thus driver oversight can be minimized.

(a) Turning left at an intersection (b) Merging into a highway

Figure 4
Sample of driver views in a variety of situations.

7. Future issues to be addressed

We consider that the following issues must be dealt with to popularize our wraparound view monitor system:

7.1 Quality of images

The cameras used in our system are 30-megapixel cameras that produce NTSC output, which is a commonly used arrangement for vehicle-mounted cameras. When images are projected onto a 3-D curved surface, the area covered by each image sensor can become too wide depending on the position of the image, resulting in poor image quality. This enlargement factor depends on the number of pixels of each camera and on the number of pixels of the output image to be synthesized. Current dashboard monitors have 800 × 480 pixels or less, which would cause few problems in terms of image quality, but image quality may need to be improved as higher precision monitors with wider screens become available.

7.2 Delay in display

There is a delay in display, that is, a difference between what is occurring around the vehicle and what is displayed on the monitor. This is no problem when traveling at low speed such as when parking, but it does pose some problems when, in the future, the wraparound view monitor is used when traveling at medium to high speed because this delay is likely to increase the risk of an accident. Since, in the current system, the MB86R01 processes image data from the four cameras, which are not synchronized, it is necessary to have a buffer memory which waits until the images from the four cameras are all in. The delay, therefore, includes both a processing delay in the MB86R01 and a wait time in the buffer.

We consider that using an 1394 Automotive (former IDB-1394) in-vehicle network to transmit multiple video images is a promising way to deal with these problems.[7),8)] 1394 Automotive has a maximum transmission rate of 800 Mb/s, and we can compress the video images to one-fourth of their original size by using a video compression technology called SmartCODEC. This technology can achieve video transmission without jumpiness or delays even when higher resolution cameras are used in the future for improving video image quality. In addition, since the 1394 Automotive network eliminates the need for a buffer memory, not only can delays be minimized but also costs can be reduced. The 1394 Automotive network was originally intended for use in an automotive navigation system and for rear seat entertainment (RSE). But its use is expected to expand to applications for, among other things, high-resolution cameras for such devices as the wraparound view monitor.

8. Conclusion

We developed a wraparound view monitor to let the driver see views all around his vehicle from the optimum point of view, or any point of view he desires, in accordance with the driving situations. We installed this technology on a test board of an MB86R01 SoC graphics controller for automobiles supplied by Fujitsu Microelectronics. Real-time synthesis of the images from the four cameras and smooth interpolation of different points of view were successfully tested. Then we built a prototype wraparound view monitor system in a test vehicle and conducted a series of road tests, in which we confirmed the feasibility of applying this system to a variety of driving situations.

We plan to develop commercial applications of this technology as an image solution and a vehicle-mounted viewing assistance system, using both the SoC graphics controller for automobiles and proper image processing software. We believe that the image processing technology we have developed will become increasingly popular as demand for vehicle-mounted cameras grows on a global basis.

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