Ray Capture Systems for FTV

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***Abstract*— FTV (Free-viewpoint Television) is an innovative visual media that allows users to view a 3D scene by freely changing their viewpoints. Thus, it enables realistic viewing and free navigation of 3D scenes. FTV is the ultimate 3DTV with infinite number of views and ranked as the top of visual media. FTV is not a conventional pixel-based system but a ray-based system. Ray capture, processing and display technologies have been developed for FTV. Here, three types of ray capture systems are presented. They are multi-camera ray capture with view interpolation, all-around dense ray capture without view interpolation and computational ray capture by reduced number of pixel data.**

I. INTRODUCTION

FTV (Free-viewpoint Television) [1]-[15] is an innovative visual media that enables users to view a 3D scene by freely changing their viewpoints as if they were there. Its feasibility was verified with the world's first real-time FTV system including the complete chain of operation from capture to display [16].

FTV delivers infinite number of views since the viewpoint can be placed anywhere. Therefore, FTV is regarded as the ultimate 3DTV. Furthermore, FTV could be the best interface between human and environment and an innovative tool to create new types of content and art.

FTV enables realistic viewing and free navigation of 3D scenes. Thus, FTV became the key concept of 2022 FIFA World Cup bidding to Japan though the bid was not successful. Japan planned to deliver a 3D replica of soccer stadium to all over the world by FTV.

All ray information of a 3D space has to be transmitted to the receiver side to realize FTV. This is very challenging and needs new technologies. FTV was realized based on the ray-space method [17]-[20]. Ray technologies such as ray capture, processing, and display have been developed for FTV. An all-around ray-reproducing 3DTV [21] was also realized by using these technologies.

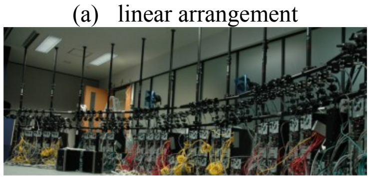
In this paper, three types of ray capture systems of FTV are presented.

II. MULTI-CAMERA SYSTEM

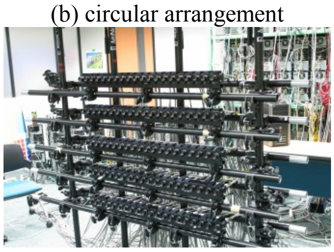
A. *100-Camera System*

Multi-camera systems are used to capture rays of large 3D space. One of them is a "100-camera system" [22]. The system consists of one host-server PC and 100 client PCs (called 'nodes') that are equipped with JAI PULNiX TM-1400CL cameras. The interface between camera and PC is Camera-Link. The host PC generates a synchronization signal and distributes it to all of the nodes. This system is capable of capturing not only high-resolution video with 30 fps but also analog signals of up to 96 kHz. The camera setting is flexible as shown in Fig. 1.

(a) linear arrangement



(b) circular arrangement



(c) 2D-array arrangement

Fig. 1. 100-camera system

The geometric correction [23], [24] and color correction [25] of captured views are needed to compensate misalignment of cameras and difference of camera characteristics.

B. *View Interpolation*

Multi-camera systems need view interpolation to obtain dense ray-space since cameras cannot be set very closely. Several interpolation methods based on depth estimation have been proposed [26]-[30]. Global optimization techniques such as Dynamic Programming (DP), Multi-Pass Dynamic Programming (MPDP), Belief Propagation (BP) and Graph Cuts (GC) give better depth estimation. However, they take more time for computation.

Figure 2 shows dependence of PSNR of interpolated images on maximum disparity for various interpolation methods. The PSNR decreases in accordance with the increase of maximum disparity for any interpolation method. However, the magnitude of PSNR strongly depends on the interpolation method. Therefore, the development of interpolation methods with higher performance is very effective to increase camera interval and hence to decrease the number of cameras.

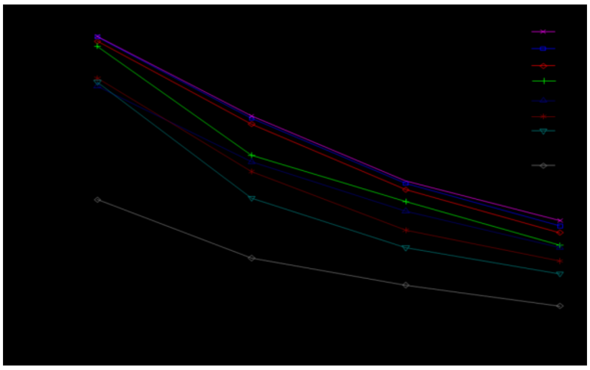


Fig. 2. Dependence of PSNR of interpolated images on maximum disparity.

Fig. 3 shows dependence of computational time of view generation on maximum disparity for various interpolation methods. Computational time increases in accordance with maximum disparity. “MPDP fast” [30] gives small computational time and high PSNR.

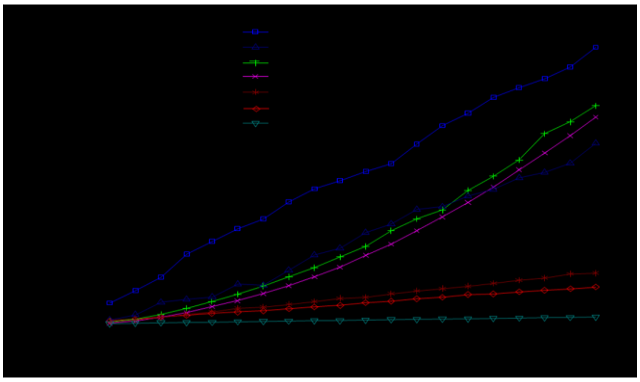


Fig. 3. Dependence of computational time of view generation on maximum disparity.

III. MIRROR-SCAN SYSTEM

3 mirror-scan systems are developed for dense ray capture without interpolation.

A. Parabolic Mirror System

Figure 4 shows a mirror-scan system for 360-degree dense ray capture [31]. This system uses two parabolic mirrors. Incident rays parallel to the axis of a parabolic mirror gather at the focus. Hence, rays that come out of an object placed at the focus of the lower parabolic mirror gather at the focus of the upper parabolic mirror. Then, a real image of the object is generated at the focus of the upper parabolic mirror and scanned by a rotating aslope mirror. The image from the aslope mirror is captured by a high-speed camera. Thus, this system can capture all-around dense rays from the object.

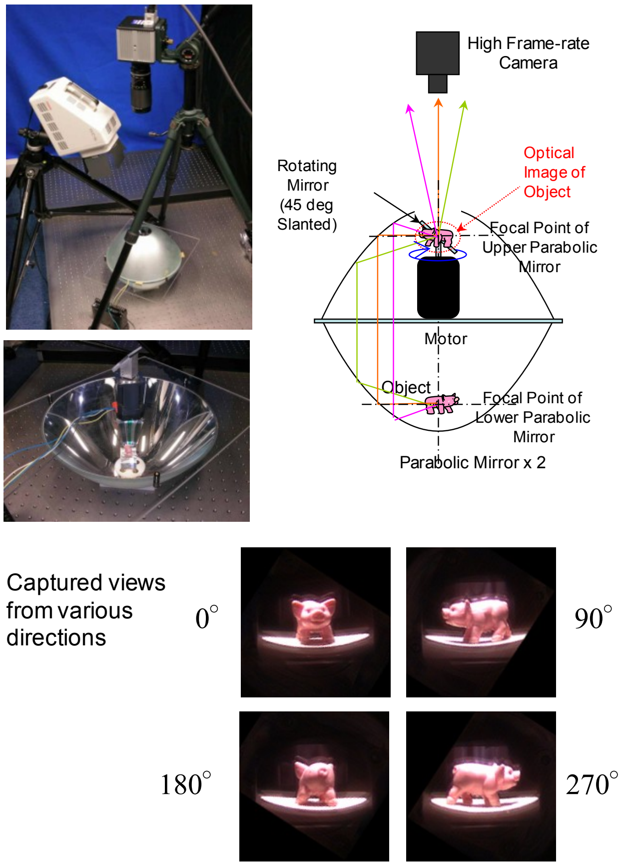


Fig. 4 Parabolic mirror system and captured views.

B. Ellipsoidal Mirror System for Size-Reduced Ray Capture

Since the parabolic mirror system needs a scanning mirror with the same size as the object, a new ray capture system that captures all-around dense rays by scanning reduced-size images is proposed [32]. As shown in Fig. 5, the proposed system consists of two ellipsoidal mirrors, a high-speed camera, and a rotating aslope mirror. Two ellipsoidal mirrors have different size and ellipticity. The mirror 1 with smaller ellipticity is set over the mirror 2 with larger ellipticity, keeping the major axes in a vertical line. The lower focus of mirror 1 and the upper focus of mirror 2 are set at the same location. The aslope mirror is placed at the upper focus of the ellipsoidal mirror 1. The high speed camera above the ellipsoidal mirror 1 captures the rays reflected by the aslope mirror.

When an object is set at the lower focus of the ellipsoidal mirror 2, rays from the object go as shown in Fig. 6 and the real image with smaller size than the object is formed at the upper focus of the ellipsoidal mirror 1. The object and captured view are shown in Fig. 6. Rays from the object are captured by the size-reduced image. However, the size-reduced image is largely distorted.

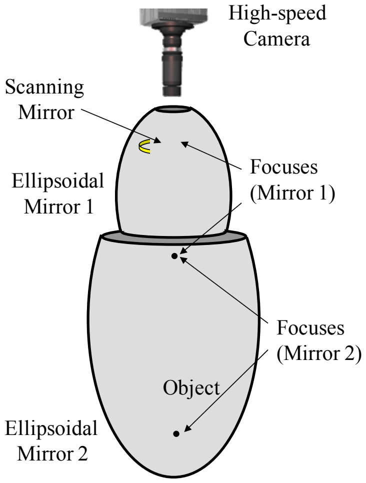


Fig. 5 Ellipsoidal mirror system for size-reduced view capture.

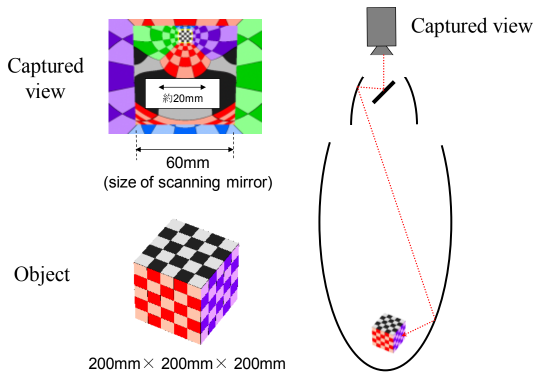


Fig. 6 Object and size-reduced captured view of ellipsoidal mirror system.

C. *Slanted Ellipsoidal Mirror System for Size-Reduced Ray Capture with less Distortion*

To reduce the distortion, a slanted ellipsoidal mirror system is proposed [33]. It consists of two ellipsoidal mirrors. However, the lower mirror is obtained by rotating a slanted ellipsoid as shown in Fig. 7. The paths of rays passing the lower focus P of the slanted ellipsoidal mirror are shown in Fig. 7. When an object is placed at the center of the bottom of the system, this system captures rays as if a camera is set at the point P.

Fig. 8 shows an ideal view and a captured view of the slanted ellipsoidal mirror system. It is seen that distortion is greatly reduced compared to the captured view of the ellipsoidal mirror system as shown in Fig. 6.

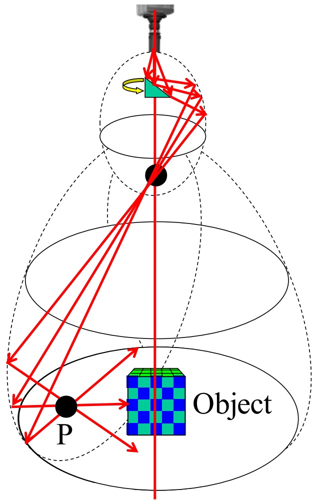


Fig. 7 Slanted ellipsoidal mirror system and paths of rays.

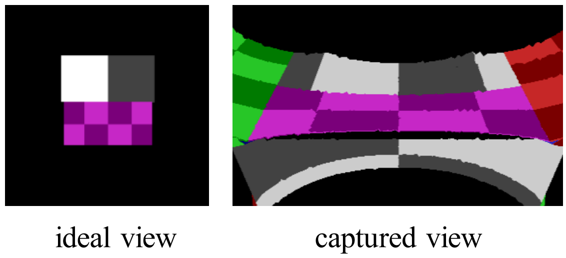


Fig. 8 Ideal view and captured view of slanted Ellipsoidal mirror system.

IV. COMPUTATIONAL SYSTEM

Efficient ray capture that acquires rays efficiently with reduced number of pixel data is presented for orthogonal and spherical ray-spaces.

A. *Efficient Capture of Orthogonal Ray-Space*

The proposed method is based on Radon transform [34]. Radon transform is the integral transform consisting of projection data and extracts wave patterns along the projecting direction. In the proposed method, the sum of brightness values of rays at various points with different depths is acquired by varifocal lenses and photodiodes as shown in Fig. 9. A lens focuses a group of rays passing one point on a photodiode and the photodiode captures the total brightness of the focused rays. Since a group of rays passing one point form a straight line on EPI (Epipolar Plane Image) and the points with different depths correspond to the straight lines with different slopes on EPI, the photodiodes on a horizontal line acquire the projection data of EPI. This process is equivalent to Radon transform of EPI. Therefore, EPI is obtained by the inverse Radon transform of the photodiode output. Ray-space is obtained by stacking EPIs vertically.

This process is simulated under the condition shown in Fig. 10. Ray-space is successfully acquired with about 1/8 of pixel data by the proposed system as shown in Fig. 11.

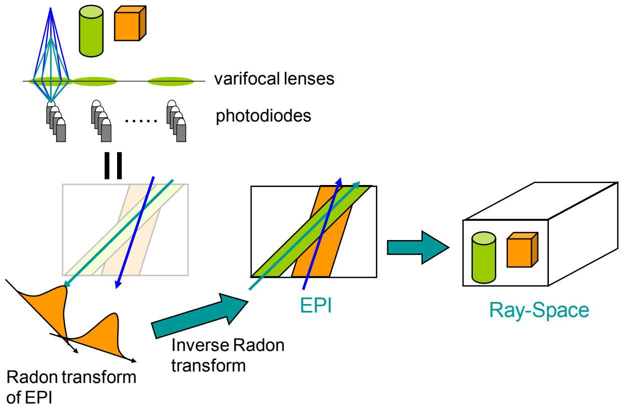


Fig. 9 Efficient ray acquisition using Radon transform for orthogonal ray-space.

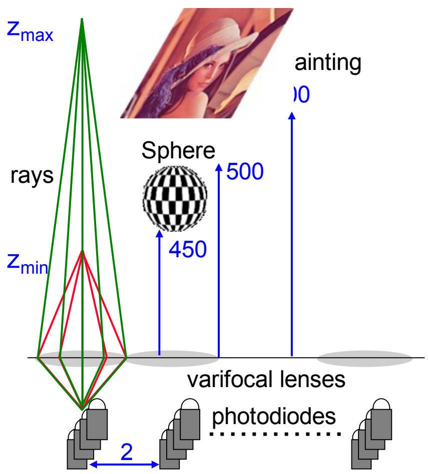


Fig. 10. Condition for simulation.

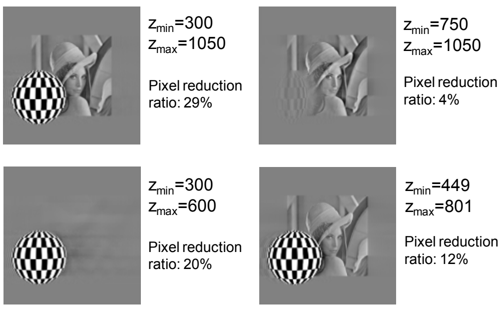


Fig. 11. Reproduced views for various capture conditions.

B. *Efficient Capture of Spherical Ray-Space*

Efficient capture of spherical ray-space is proposed [35]. It uses the sinusoidal structure of EPI of spherical ray-space. Each EPI of spherical ray-space is transformed into an amplitude-phase domain image by integrating the value of EPI along sinusoidal waves with various amplitudes and phases. Fig. 12 shows an example of the transformation. The integration along a red sinusoidal wave in the left image in Fig. 12 gives a red point in the right image. The right image is obtained by repeating this for sinusoidal waves with various amplitudes and phases.However, as seen in Fig. 12, this transform gives a half size of output image compared with an input image.

To obtain the same size of output image, we obtain 2 output images by integrating the increasing and decreasing parts of sinusoidal waves. Thus, we obtain the same size of output image as shown in Fig. 13.

EPI is successfully reproduced from the amplitude-phase domain image by an iteration method as shown in Fig. 14. Fig. 15 shows original and reproduced images.

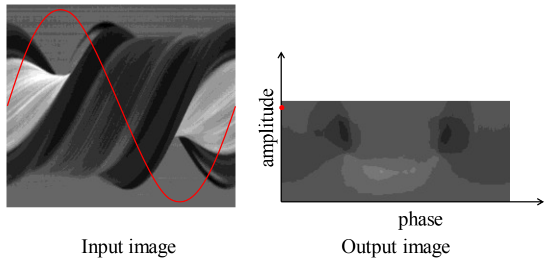


Fig. 12. Principle of transformation.

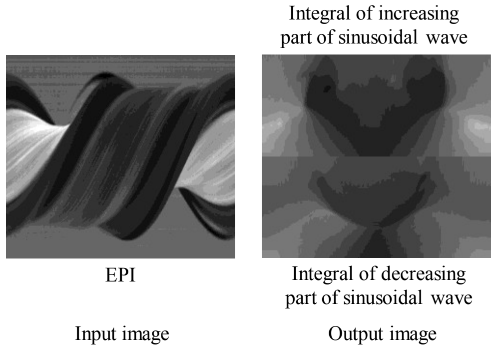


Fig. 13. Amplitude-phase transform

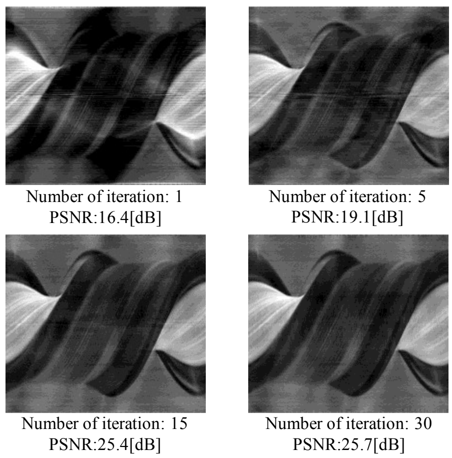
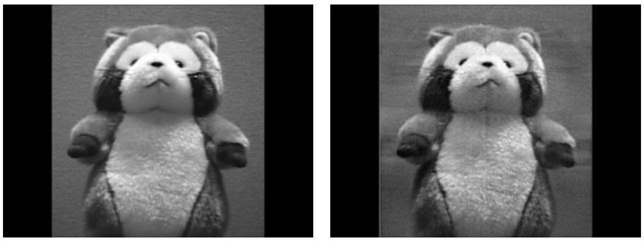


Fig. 14. Reproducing process by iteration.



original image reproduced image

Fig. 15. Original and reproduced images.

V. CONCLUSIONS

Three types of systems, multi-camera system, mirror-scan system and computational system, have been developed for ray capture.

Multi-camera system can capture a large 3D space. However, it needs many cameras and view interpolation to obtain dense ray space. Interpolation methods based on more accurate depth estimation is very effective to increase camera interval and hence to decrease the number of cameras.

Mirror-scan system can capture all-around dense rays without view interpolation. However, it can’t capture a large 3D scene because it is difficult to rotate a large mirror. To capture an object such as a human face, size-reduced mirror scan systems have been developed. Although they can capture a larger object than the rotating mirror, captured views have distortion. It should be reduced further.

Two types of computational systems have been proposed for orthogonal ray-space and spherical ray-space. They consist of varifocal lenses and photodiodes. Computer simulation shows that they can capture rays efficiently with reduced number of pixel data.

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