Quality and Performance Evaluation of Ray-Space Interpolation for Free Viewpoint Video Systems

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Abstract. Ray-space is the main technology to realize Free Viewpoint Video (FVV) systems with complicated scenes. One of the key technologies to make the ray-space feasible is interpolation. In this paper, two fast interpolation methods based on feature points and directionality detection are compared with block based matching method, and the experimental results show that the two methods improve visual quality as well as *PSNR*s of rendered virtual viewpoint image greatly while computational burden is also reduced significantly.

1 Ray-Space Interpolation for Free Viewpoint Systems

In the application scenario of free viewpoint video (FVV) systems, the viewers experience the free viewpoint navigation within the range covered by the shooting cameras. In recent years, image based rendering techniques have been developed to generate novel views of an environment from a set of pre-acquired images. Ray-space representation, as a new technique of image based rendering, renders arbitrary viewpoint images without complicated object segmentation and 3D modeling. However, in real world situation, it is difficult to set many cameras very closely, and the ray data obtained by the camera setup is too sparse in viewpoint axis to apply the ray-space method [1]. Therefore, it is necessary to generate dense ray data by interpolation techniques. It should be noted that ray-space slice has strong directionalities, so that conventional interpolation methods developed for natural image are not suitable anymore. Directionality detection of each pixel to be interpolated becomes very important in ray-space interpolation. Because ray-space interpolation is in fact associated with arbitrary intermediate view rendering, it is one of the key technologies in ray-space based FVV systems.

The block-based matching method (BMI) consists of searching for corresponding blocks in the two EPI lines (epipolar lines) to find the best-corresponding pixel pair for interpolation in the assigned maximum disparity [2]. Our directionality detection based method (DDI) [3] and feature point growth based method (FGI) [4] are two feature based interpolation methods. In DDI and FGI, feature pixels are first extracted from sparse ray-space slice, and their directionalities are determined by block matching technique, then directionality of each pixel to be interpolated in dense ray-space

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slice is linear interpolated with the directionalities of these feature pixels, and then linear interpolation is done according to directionality of the pixel to be interpolated. In fact, the so-called feature pixel is the one near edge or within area with fine texture. Directionality searching is only done for these feature pixels, because these searching usually can obtain more reliable results compared with processing of non-feature pixels around which there is no enough texture information for marching. Moreover, the computational burden is also reduced because the matching is done only for feature pixels but not all pixels to be interpolated. Different from DDI method, FGI method is proposed to solve the occlusion problem further. In FGI, each of the feature points grows in the nearby epipolar lines until the direction of the grown feature point departures from the direction of the initial point, which means that occlusion occurs or the feature point is in fact a noise.

2 Experimental Results and Analysis

To compare the above three methods, we perform experiments on two test sequences of real data called “Xmas” and “Cup” as given in Fig.1 on a PC with CPU of 1.8G Hz and RAM of 256M. “Xmas” sequence is provided by Tanimoto Laboratory, Nagoya University, 101 viewpoint images are captured synchronously with camera interval of 3mm, the image resolution is 640×480, and the distance between cameras and object is about 30cm. The “Cup” sequence is captured by a shifted camera with interval of 1mm, the number of viewpoint images and the resolution are the same as “Xmas” sequence, distance between camera and object is about 20cm, so the maximum disparity in “Cup” sequence is much larger than “Xmas” sequence.

(a) “Xmas” (b) “Cup”

Fig. 1. The original left-most and right-most viewpoint images of the two test sequences

The EPI obtained from the 101 images is adopted as the dense EPI, while the EPI transformed from some images with same camera interval is used to simulate the sparsely sampling. To evaluate the performance of ray-space interpolation method, the interpolated EPI is compared with the corresponding dense one, and the rendered intermediate viewpoint images are also compared with the real captured images.

Table 1 gives the average *PSNR*s of the 480 interpolated EPIs as well as the corresponding average interpolating times. It is clear that the DDI and FGI methods achieve much higher *PSNR*s than BMI method. The interpolating time of the BMI method increases as camera interval increases, but the proposed methods consume approximately constant time under different camera intervals, and the interpolating time is much saved compared with BMI method especially under large camera interval.

Table 1. Average *PSNR* / Interpolating time of 480 EPIs unit: dB / ms

Test sets	Camera interval	BMI	DDI	FGI
Xmas	15mm	39.31 / 97	40.69 / 28	41.03 / 34
	30mm	38.81 / 185	39.59 / 28	40.27 / 36
	60mm	37.72 / 354	38.60 / 29	39.72 / 37
	75mm	36.60 / 438	38.07 / 29	39.50 / 38
Cup	5mm	33.84 / 165	34.27 / 26	34.89 / 36
	10mm	33.11 / 335	33.60 / 25	34.23 / 39
	20mm	31.58 / 672	32.68 / 26	33.50 / 41
	25mm	30.35 / 839	31.36 / 25	31.99 / 41

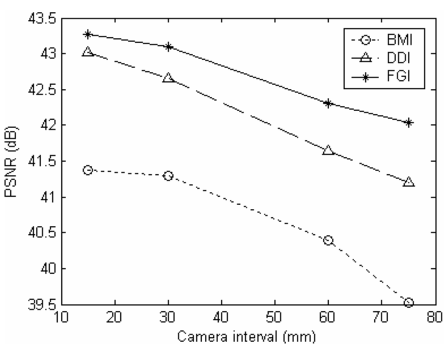
(a) Original dense EPI

(b) BMI (PSNR=30.29dB)

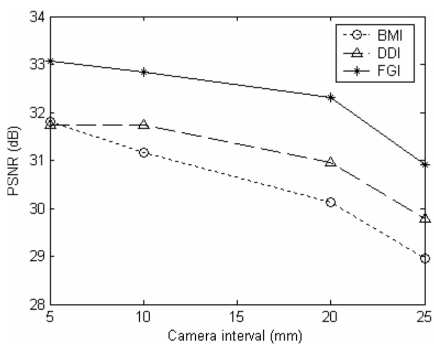
(c) DDI (PSNR=32.03dB)

(d) FGI (PSNR=32.29dB)

Fig. 2. Results of the interpolated 155th EPI with camera interval 25mm (from "Cup" sequence)



(a) "Xmas"



(b) "Cup"

Fig. 3. Average *PSNR*s of rendered intermediate viewpoint images

Fig.2 gives an example of ray-space interpolation with the three different methods. Fig.3 shows average *PSNR*s of intermediate viewpoint images rendered from the interpolated ray-space. In the figures, the proposed interpolation methods outperform BMI method, because it can obtain more accurate directions. Moreover, the proposed methods run much faster than BMI method because it only searches some feature points' directions but not all of the pixels to be interpolated. Fig.4 shows parts of the rendered viewpoint images with respect to the above three interpolation methods. The text and the door's edges on the cup are well kept by the proposed methods, it is obvious that the proposed methods are much better than BMI method in keeping

(a) Original image (b) BMI (29.35dB) (c) DDI (30.99 dB) (d) FGI (32.74dB)

Fig. 4. Part of the rendered 40th virtual view from interpolated ray-space with camera interval 25 mm (from "Cup" sequence)

edges and fine textures of objects. After generating dense ray-space, it is easy to render stereo images by selecting appropriate data.

3 Conclusions

Ray-space representation has superiority in rendering arbitrary viewpoint images of complicated scene in real-time. Interpolation is one of the key techniques to make the ray-space based FVV system feasible, and it also determines the cost of application and the quality of rendered image. In this paper, two fast interpolation methods based on feature points and directionality detection are compared with block based matching method, and it is seen that the two methods improve visual quality as well as *PSNR*s of rendered virtual viewpoint image greatly while computational burden is also reduced significantly.

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