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Visual comfort enhancement in stereoscopic 3D images using saliency-adaptive nonlinear disparity mapping ☆

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ABSTRACT

Perceptually salient regions have a significant effect on visual comfort in stereoscopic 3D (S3D) images. The conventional method of obtaining saliency maps is linear combination, which often weakens the saliency influence and distorts the original disparity range significantly. In this paper, we propose visual comfort enhancement in S3D images using saliency-adaptive nonlinear disparity mapping. First, we obtain saliency-adaptive disparity maps with visual sensitivity to maintain the disparity-based saliency influence. Then, we perform nonlinear disparity mapping based on a sigmoid function to minimize disparity distortions. Finally, we generate visually comfortable S3D images based on depth-image-based-rendering (DIBR). Experimental results demonstrate that the proposed method successfully improves visual comfort in S3D images by producing comfortable S3D images with high mean opinion score (MOS) while keeping the overall viewing image quality.

1. Introduction

Stereoscopic three-dimensional (S3D) media provides a more life-like and visually immersive viewing experience, and is regarded as a next generation media [1]. With the rapid advances in the multimedia technology, users can easily access S3D contents even at home. However, for their great success, the viewing safety, especially visual comfort of S3D contents should be ensured, which becomes a growing issue of concern. Visual discomfort in S3D images is often induced by several factors [2,3] such as excessive disparities, fast changes in disparity, disparity distribution, depth inconsistency, perceptual and cognitive inconsistency, the accommodation–vergence conflict, the mismatches in the left and right images, depth cue conflicts. It is necessary to improve the visual comfort in S3D images.

1.1. Related work

In most previous studies, the visual comfort in S3D images is quantified by global disparity statistics. It has been reported that excessive disparities cause visual discomfort in S3D images because regions with larger disparities are hard to fuse on retina [2]. That is, humans feel more visual discomfort on S3D images with the excessively pop-out objects than those with the constant depth plane. In Refs. [4,5], the statistics of disparity such as mean and standard deviation of disparity value were measured over the entire image, and applied to the visual comfort assessment (VCA). However, they were not fully correlated with human visual perception. Human tends to pay more attention to a few but salient regions than the others in an image [6–8]. That is, visual saliency has a significant influence on the perceptual quality of S3D images. Therefore, perceptually salient regions are a key factor to determine the visual comfort in S3D images including the disparity statistics [7]. In S3D displays, depth information also plays an important role in attracting human visual attention. It has been reported that the density of fixations by the human visual system (HVS) increases for objects with larger disparity magnitudes [9]. That is, humans often fixate on near objects earlier than far away ones [10]. Thus, a visual importance map is generated by the linear combination of image-based saliency and disparity-based saliency maps, then the visual importance map is used as a weight of extracted disparity features to complete the visual comfort assessment [11]. With regard to visual comfort enhancement, there are mainly two disparity mapping approaches to reduce visual discomfort caused by excessive disparities. One is the disparity scaling [12] while the other is disparity shifting [13,14]. The disparity scaling (linearly or non-linearly) reduces visual comfort in S3D images by scaling down the disparity range of an original

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scene into the target range. In previous studies, there are many ways to scale the disparity range of the scene into the visual comfort zone such as depth image-based rendering (DIBR) and stereoscopic warping-based rendering [15]. The disparity scaling method is a promising tool for improving visual comfort. However, it tends to produce rendering artifacts, and the image size is also reduced after the disparity scaling. Thus, we need interpolation to enlarge the scaled image to the original size, which inevitably degrades the image quality. The disparity shifting adjusts disparity by laterally shifting the left and right images which move the zero display plane (ZDP) of the original image. However, when the disparity range of the image exceeds the range of a certain comfortable viewing zone, it is hard to reduce the visual comfort. Moreover, both disparity scaling and disparity shifting are not fully correlated with human visual perception. Thus, a visual importance map is additionally considered in visual comfort enhancement in Ref. [16]. However, the linear combination of image-based saliency and disparity-based saliency weakens the disparity-based saliency effect mainly related to visual comfort, and distorts the original disparity range significantly.

1.2. Contributions

In this paper, we propose visual comfort enhancement in S3D images using sensitivity-weighted saliency-adaptive nonlinear disparity mapping. Image-based saliency mainly represents visual attention where is attractive to the human eye, while disparity effectively expresses visual comfort in S3D images because excessive binocular disparity often causes visual fatigue. Thus, simple linear combination of image-based saliency and disparity-based saliency often weakens the saliency effect and distorts the original disparity range significantly. Previous work [17] has reported that there exist sensitive and insensitive regions in images to HVS [17]. HVS actively perceives the orderly contents of the input visual information and tries to avoid some uncertainties for image perception. As a result, HVS is sensitive to orderly regions which possess regular structures, but insensitive to disorderly regions which possess uncertain structures. HVS differently perceives sensitive and insensitive regions according to structural uncertainty. The saliency detection should be based on the human visual perception of image content. Thus, we adopt a sensitivity-weighted saliency-adaptive disparity map instead of the linear combination of image-based saliency and disparity-based saliency to maintain the effects of sensitivity, disparity- and image-based saliency and preserve the original visual comfort disparities. The sensitivity-weighted saliency-adaptive disparity map is obtained by using sensitivity and image-based saliency as a weight for disparity map. Moreover, we perform nonlinear disparity mapping based on a sigmoid function to minimize disparity distortions and produce perceptually comfortable S3D images.

Fig. 1 illustrates the overall framework of the proposed method. First, we obtain sensitivity-weighted saliency-adaptive disparity maps to maintain the effects of sensitivity and saliency as well as preserve the original visual comfort disparities. Then, we perform nonlinear disparity mapping based on a sigmoid function to minimize disparity distortions in S3D images. Finally, we produce the visually comfortable S3D images using depth-image-based-rendering (DIBR).

The remainder of this paper is organized as follows. In Section 2, we explain the proposed method for visual comfort enhancement in detail. In Section 3, we provide experimental results and their corresponding analysis. Conclusions are made in Section 4.

2. Proposed method

The proposed framework consists of six main steps: (1) Disparity estimation using the depth estimation reference software (DERS), (2) sensitivity estimation using pattern masking, (3) saliency estimation by graph-based visual saliency (GBVS), (4) sensitivity-weighted saliency-adaptive disparity generation, (5) nonlinear disparity mapping, and (6) depth-image-based rendering (DIBR).

2.1. Disparity estimation

In S3D displays, disparity is a key factor that induces visual discomfort. It has been reported that excessive disparities cause visual discomfort in S3D images because regions with larger disparities are difficult to fuse on retina [2]. That is, humans feel more visual discomfort on S3D images with the excessively pop-out objects than those with the constant depth plane. Previous studies have reported that visual discomfort increases as disparity increases [18]. Thus, we estimate a disparity map D for the right view using DERS in Ref. [19]. Fig. 2(c) shows the disparity maps of Fig. 2(a) and (b) obtained by DERS.

2.2. Sensitivity estimation

Previous work has reported that there exist sensitive and insensitive regions in images to HVS [17]. HVS actively perceives orderly

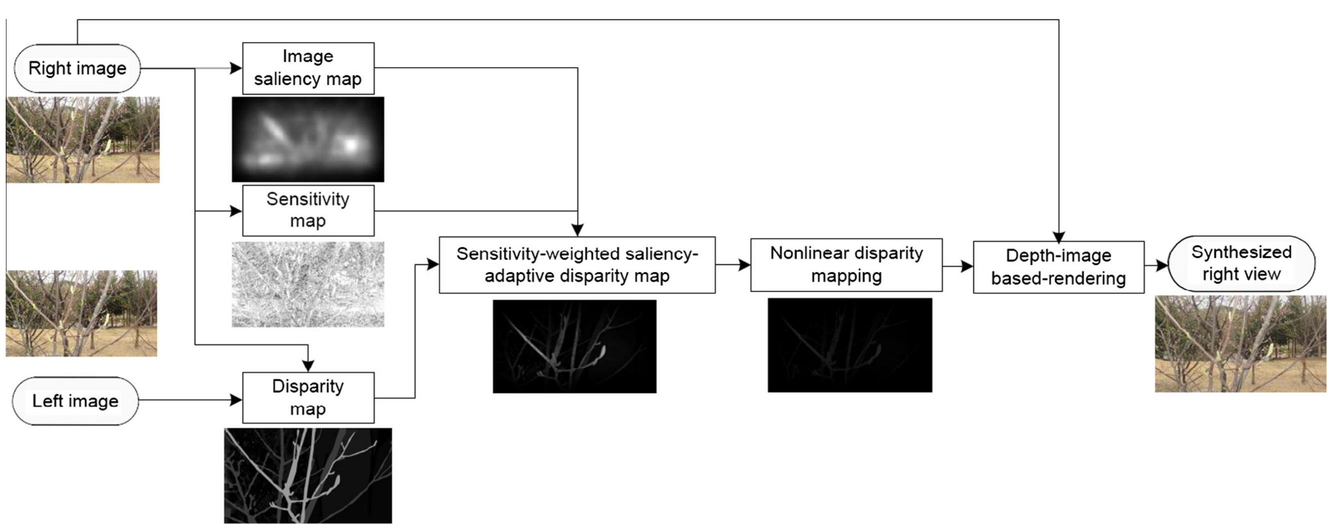

Fig. 1. The overall framework of the proposed method.