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Predict the Quality of Distorted Stereoscopic Images in Asymmetric 3D

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Abstract— Objective quality assessment of distorted stereoscopic images is a challenging problem, especially when the distortions in the left and right views are asymmetric. Existing studies suggest that simply averaging the quality of the left and right views well predicts the quality of symmetrically distorted stereoscopic images, but generates substantial prediction bias when applied to asymmetrically distorted stereoscopic images. In this paper, we first build a database that contains both single-view and symmetrically and asymmetrically distorted stereoscopic images. We then carry out a subjective test, where we find that the quality prediction bias of the asymmetrically distorted images could lean toward opposite directions (overestimate or underestimate), depending on the distortion types and levels. Our subjective test also suggests that eye dominance effect does not have strong impact on the visual quality decisions of stereoscopic images. Furthermore, we develop an information content and divisive normalization-based pooling scheme that improves upon structural similarity in estimating the quality of single-view images. Finally, we propose a binocular rivalryinspired multi-scale model to predict the quality of stereoscopic images from that of the single-view images. Our results show that the proposed model, without explicitly identifying image distortion types, successfully eliminates the prediction bias, leading to significantly improved quality prediction of the stereoscopic images.

I. INTRODUCTION

OVER the past years, we have observed an exponential increase in the demand for 3D image and video services. High-quality 3D movies can now be seen in thousands of new generation 3D theaters all around the world. Meanwhile, 3D TV has become technologically mature and won an increasing market share in the consumption market since 2011, where non-cinematic 3D

contents could be from Blu-ray 3D or 3D broadcasting It is expected that mobile phones will be the largest 3D display application on a unit shipment basis in 2018, when 71 million units will have 3D capability. Nevertheless, automatically assessing the quality of 3D visual experience is a challenging problem due to the complex and non-intuitive interactions between multiple 3D visual cues including image quality, depth quality and visual comfort. As a result, recent progress on 3D image quality assessment (IQA) remains limited. This lack of successful objective IQA methods for 3D visual experience has limited the development of 3D imaging applications and services. In this work, we focus on how to predict the quality of a stereoscopic 3D image from that of the 2D single-view images. First, we carry out a subjective quality assessment experiment on a database that contains both single-view images and stereoscopic images with symmetric and asymmetric distortion types and levels. This database allows us to directly study the quality prediction performance from single-view images to stereoscopic images, for which we observe that simply averaging the quality of both views creates substantial bias on asymmetrically distorted stereoscopic images, and interestingly, the bias could lean towards opposite directions, largely depending on the distortion types. We then develop an information content and divisive normalization based pooling scheme that improves upon SSIM in estimating the quality of single-view images. Furthermore, by incorporating spatial frequency tuned mechanisms of human visual system (HVS), we propose a binocular rivalry inspired model to account for the bias, which not only results in better quality prediction of stereoscopic images with asymmetric distortion levels, but also well generalizes to the case of asymmetric distortions with mixed distortion types.

II. REVIEW OF PREVIOUS 3D-IQA STUDIES

A. Previous Subjective 3D-IQA Studies

To the best of our knowledge, there are currently 8 subjectrated image databases that are commonly recognized in the 3D-IQA research community. Quality Assessment Database are publicly available. Subjective data is essential in understanding the impact of various distortions on the perceptual quality of stereoscopic images. Ideally, we would need a complete set of subjective test on an image database that contains both 2D (single-view) and stereoscopic 3D images, both symmetrically and asymmetrically distorted images at different distortion

levels, as well as both single- and mixed-distortion images. The above-mentioned existing 3D image quality databases are highly valuable but limited in one aspect or another. Specifically, IRCCyN/IVC 3D Images Database, Tianjin University Database, Ningbo University Database Phase II, and LIVE 3D Image Quality Database Phase I only include symmetrically distorted stereoscopic images. Ningbo University Database Phase I only includes asymmetrically distorted stereoscopic images. MICT 3D Image Quality Evaluation Database contains both cases but only for JPEG compressed images. The most recent LIVE 3D Image Quality Database Phase II includes both symmetric and asymmetric cases as well as five distortion types. Unfortunately, 2D-IQA of single-view images are missing, making it difficult to directly examine the relationship between the perceptual quality of single-views and stereoscopic images. In addition, asymmetric distortions with mixed distortion types are missing in all existing databases, making it hard to validate the generalization capability of 3D quality prediction models.

B. Previous Objective 3D-IQA Studies

Existing objective 3D-IQA or 3D video quality assessment (3D-VQA) models may be grouped into two categories. The first type of approaches are built directly upon successful 2D-IQA methods. These approaches can be further divided into two subcategories, depending on the use of depth or disparity information. Methods in the first subcategory do not explicitly use depth information. In 2D-IQA measures, including peak-signal-to-noise ratio (PSNR), structural similarity (SSIM) and video quality metric (VQM) were applied to the left- and right-view images of 3D videos separately and then combined to a 3D quality score. Both experimental results showed that VQM performs better than PSNR and SSIM possibly due to the temporal considerations in VQM. In PSNR and VSSIM which is a version of SSIM adapted for video, were compared to measure the perceptual 3D quality and the VSSIM was found to be closer to the subjective evaluation results. In four 2D-IQA metrics, namely SSIM, universal quality index (UQI) [20], C4 and RRIQA as well as three approaches, called average approach, main eye approach, and visual acuity approach, were tested for measuring the perceptual quality of stereoscopic images. The experimental results show that C4 outperforms the other three metrics on IRCCyN/IVC 3D Images Database. The second subcategory of methods incorporates

depth information with 2D-IQA. In [7] and [23], disparity maps between leftand right-views were estimated, followed by 2D quality assessment of disparity quality using SSIM and C4, which was subsequently combined with 2D image quality to produce an overall 3D image quality score. The results claimed that C4 outperforms SSIM on both evaluating stereoscopic image pairs and disparity maps on IRCCyN/IVC 3D Images Database and also suggested that the 3D-IQA performance of SSIM can be improved when adding depth quality. You et al. [24] investigated the capabilities of evaluating stereopairs as well as disparity maps with respect to ten wellknown 2D-IQA metrics, i.e., PSNR, SSIM, multi-scale SSIM (MS-SSIM) [25], UQI, visual information

fidelity (VIF) [26], etc. Their results suggested that an improved performance can be achieved when stereo image quality and depth quality are combined appropriately. Similarly, Yang et al. proposed a 3D-IQA algorithm based on the average PSNR of left- and right-views and the absolute difference with respect to disparity map. However, none of these more sophisticated 3D-IQA models perform better than or in most cases, even as good as, direct averaging 2D-IQA measures of both views

The second type of 3D-IQA or 3D-VQA approaches focus on building 3D quality models directly without relying on existing 2D-IQA algorithms. In, Gorley and Holliman computed quality scores on matched feature points delivered by SIFT and RANSAC The experimental results showed that the stereo band limited contrast model performs better than PSNR. In, an estimation of stereo image quality was proposed based on a multiple channel HVS model. In Zhu amd Wang proposed a 3D-VQA model by considering depth perception and their experimental results showed that it performs better than MSE and PSNR. In [33], Jin et al.

C. Observations

Recent subjective studies suggested that in the case of symmetric distortion of both views (in terms of both distortion types and levels), simply averaging state-of-the-art 2D-IQA measures of both views is sufficient to provide reasonably accurate image quality predictions of stereoscopic images. In particular, it was shown that averaging PSNR, SSIM, MS-SSIM, UQI and VIF measurements of left- and right-views performs equally well or better than the advanced 3D-IQA models on LIVE 3D Image Quality Database Phase I. Similar results were also observed in [6], where

averaging SSIM and MS-SSIM measurements of both views outperformed advanced 3D-IQA models on LIVE 3D Image Quality Database Phase II. In it was reported that directly averaging MS-SSIM outperformed 3D-IQA models on Ningbo University 3D Image Quality Assessment Database Phase II.

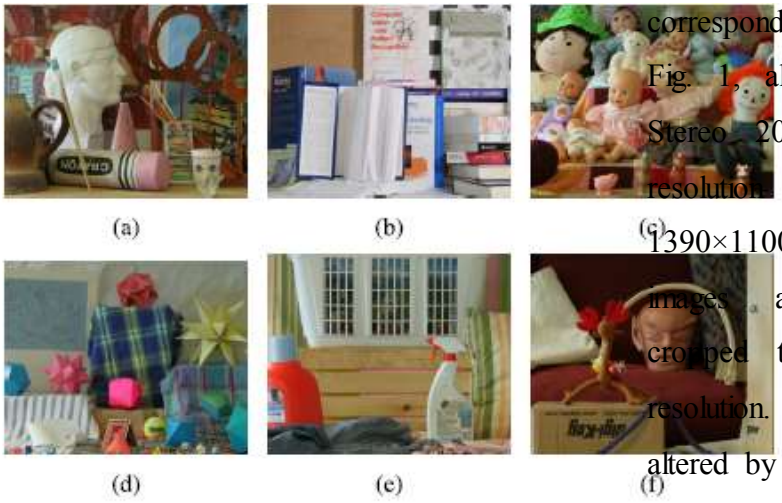

Fig. 1. The 6 pristine images in Waterloo-IVC 3D database Phase I. Only the right-views are shown here. (a) Art. (b) Books. (c) Dolls. (d) Moebius. (e) Laundry. (f) Reindeer.

Compared with the case of symmetric distortions, quality assessment of asymmetrically distorted stereoscopic images is a much more challenging problem. In [6], it was reported that there is a large drop in the performance of both 2D-IQA and 3D-IQA models from quality predictions of symmetrically to asymmetrically distorted stereoscopic images on LIVE 3D Image Quality Database Phase II.

III. SUBJECTIVE STUDY

A. Waterloo-IVC 3D Image Quality Database Phase I

The new Waterloo-IVC 3D Image Quality database Phase I is created from 6 pristine stereoscopic image pairs (and thus their corresponding single-view images) shown in Fig. 1, all collected from the Middlebury Stereo 2005 Datasets [44]. The original resolution of single-view images is 1390×1100 or 1342 × 1100. All single-view images and stereopairs were slightly cropped to fit a display of 1920×1080 resolution. Each single-view image was altered by three types of distortions: additive white Gaussian noise contamination, Gaussian blur, and JPEG compression. additive white Gaussian noise was applied equally across the R, G and B color channels. Similarly, Gaussian blur was simulated by applying a Gaussian low-pass filter to each of the color channels. For both noise and blur, the control parameter was the variance of the Gaussian. JPEG Compression was simulated using MATLAB®'s JPEG compression utility imwrite (Write True Color Image to JPEG). The single-view images were employed to generate distorted stereopairs, either

symmetrically or asymmetrically. Altogether, there are totally 78 single-view images and 330 stereoscopic images. Table III categorizes these images into seven groups with detailed descriptions. Group 3D.1, Group 3D.2 and Group 3D.3 cover all combinations while Group 3D.4 includes a random subset from all possible fusions. To the best of our knowledge, there are two unique features of the current database when compared with existing publicly known 3D-IQA databases. First, this is the only database that allows us to perform subjective test on both 2D and 3D images. The inclusion of 2D images allows us to directly examine the relationship between the perceptual quality of stereoscopic images and that of its single-view images. This is advantageous against previous studies which do not have ground truth of 2D image quality but have to rely on objective 2D-IQA measures to provide estimates. Second, this is the only database that contains mixed distortion types in asymmetrically distorted images. The motivation of including different asymmetrical distortion levels and various mixed distortion types is threefold. First, purely for scientific curiosity, we are interested in knowing how the HVS behaves in the cases of asymmetrical/mixed distortions. Second, asymmetrical/mixed distortions are realistic in practice. For example, in the case of multi-exposure stereo images because of the different exposure levels being used on different views, the amount of noise coming into the left- and right-view image sensors is different. For another example, asymmetric blur distortions and asymmetric blocking artifacts can be found in the case of mixed-resolution coding and asymmetric transform-domain quantization coding, and such distortions could have mixed types when postprocessing techniques (deblocking or blurring) are employed.

B. Subjective Test

The subjective test was conducted in the Lab for Image and Vision Computing at University of Waterloo. The test environment has no reflecting ceiling walls and floor, and was not insulated by any external audible and visual pollution. active shutter glasses is used for the test. The default viewing distance was 3.5 times the screen height. In the actual experiment, some subjects did not feel comfortable with the default viewing distance and were allowed to adjust the actual viewing distance around it.

C. Waterloo-IVC 3D Image Quality Database Phase II

The new Waterloo-IVC 3D Image Quality database Phase II with more diverse image content is created from 10 pristine stereoscopic image pairs (and thus their corresponding single-view images). All images were collected from previous subjective 3D quality studies and the resolution of all images is 1920 × 1080. Each single-view image was altered by the same three types of distortions and each distortion type had the same four distortion levels. The single-view images were employed to generate distorted stereopairs, either symmetrically or asymmetrically. Altogether, there are totally 130 single-view images and 460 stereoscopic images.

D. Analysis and Key Observations

The raw 2DIQ and 3DIQ scores given by each subject were converted to Z-scores, respectively. Then the entire data sets were rescaled to fill the range from 1 to 100 and the MOS scores for each 2D and 3D image was computed after removing outliers. Given the subjective data, the main question we would like to ask in the current paper is how the single-view 2D image quality predicts the 3D image quality (3DIQ scores in the subjective test), especially for the case of asymmetric distortions. The most straightforward 2D-to-3D quality prediction method is to average the MOSs of the leftand right-view images.

IV. OBJECTIVE STUDY: 2D-TO-3D QUALITY PREDICTION

We opt to use a two-stage approach in the design of an objective 3DIQ predictor. The first stage aims to evaluate the perceptual quality of single-view images, while in the second stage, a binocular rivalry inspired multi-scale model is developed to combine 2D image quality of both views into a quality estimation of 3D image quality.

A. Objective 2D Quality Assessment

In the literature, the SSIM index as well as its derivatives MS-SSIM and information content weighted SSIM (IW-SSIM) have demonstrated competitive performance in 2D objective IQA tests . An advantage of the SSIM approach is that it provides a quality map that indicates the variations of image quality over space It was shown that spatial pooling built upon the quality map based on information content weighting or distortion weighting further improves the performance . Here we build our 2D-IQA model upon SSIM, but improve it further by incorporating an information content and divisive normalization based pooling scheme. A general form of spatially weighted pooling is given by

$$Q_{2D} = \sum_{i=1}^{N} w_i q_i \Big/ \sum_{i=1}^{N} w_i, \quad (1)$$

where qi and wi are the local quality value (e.g., local SSIM value) and the weight assigned to the i -th spatial location (i -th pixel), respectively. The assumption behind information content weighted pooling is that the spatial locations that contain more information are more likely to attract visual attention, and thus should be given larger weights. Let xi and yi be the local image patches extracted around the i –th spatial location from the reference and the distorted images,

respectively. Following the information content evaluation method in we compute the weighting factor by

V. CONCLUSION

The major contributions of the current paper are as follows: First, we create a new subjective 3D-IQA database that has two unique features − the inclusion of both 2D and 3D images, and the inclusion of mixed distortion types. Second, we observe strong distortion type dependent bias when using the direct average of 2D image quality of both views to predict 3D image quality. Third, we observe that eye dominance does not have strong impact on visual quality evaluations of asymmetrically distorted stereoscopic images. Fourth, we develop an information content and divisive normalization based pooling scheme that improves upon SSIM in estimating the quality of single-view images. Fifth, we propose a binocular rivalry inspired multi-scale model to predict the quality of stereoscopic images from that of its single-view 2D images. Our results show that the proposed model, without explicitly identifying image distortion types, successfully eliminates the prediction bias, leading to significantly improved quality prediction of stereoscopic 3D images. The performance gain is most pronounced in the case of asymmetric distortions. In the future, we will extend our study to understand human opinions on depth quality, visual comfort and the overall 3D QoE, aiming to develop a complete objective quality assessment models for 3D QoE.

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WANG et al.: QUALITY PREDICTION OF ASYMMETRICALLY DISTORTED STEREOSCOPIC 3D IMAGES 3413

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