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The effect of depth map up-sampling on the overall quality of stereopairs ☆

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ABSTRACT

The quality of depth maps affects the quality of generated 3D content. Practically, the depth maps often have lower resolution than that of color images, thus, Depth map Up-sampling (DU) is needed in various 3D applications. DU can yield specific artifacts which can degrade the quality of depth maps as well as constructed stereoscopic (color plus depth map) images. This paper investigates the effect of DU on 3D perception. The depth maps were up-sampled using seven approaches and the quality of stereoscopic images obtained from up-sampled depth maps was estimated through subjective and objective tests. The objective quality prediction was performed using a depth map quality assessment framework. The method is able to predict the quality of stereoscopic images through evaluation of their corresponding up-sampled depth maps using 2D Image Quality Metrics (IQMs). In order to improve the quality estimation, the framework selects the 2D IQMs with highest correlation to subjective test. Furthermore, motivated by previous researches on multiple metrics combination, a new metric fusion method is proposed. Experimental results show that the combined metric delivers higher performance than single metrics in 3D quality prediction.

1. Introduction

Following the rapid advances of three-dimensional (3D) technologies and the demand for attractive services such as 3D television (3DTV) and Free Viewpoint Video (FVV), the success of 3D applications depends on providing high quality content. In 3D systems, depth map has an important role for 3D content generation and the 3D quality highly depends on the accuracy of depth data.

The value of each pixel in depth images determines the position of the associated color pixel in 3D space. Depth maps can be captured using Time-of-Flight (ToF) depth-sensing cameras in which an up-sampling step is needed to increase the spatial resolution of depth maps. Another method is to obtain depth maps from a pair of images with different viewpoints using stereo matching algorithms [1,2].

Depth maps are widely used in 3D transmission to save bandwidth. Fehn et al. [3] proposed to transmit color image and its corresponding depth map called 2D+Z format. The stereopairs can be generated in receiver side with Depth Image Based Rendering (DIBR) technique [4]. The 2D+Z format delivers higher transmission efficiency than stereo-pair formats since depth maps can be highly compressed [5].

Depth map should have the same spatial resolution as color image and be well aligned in object boundaries with color data. The depth maps from stereo matching methods often have some regions with unreliable depth data especially in texture-less areas and repeated patterns. Moreover, the depth edges may not be well aligned with the color image. The ToF cameras can overcome the limitations of stereo matchers and provide more accurate depth estimation independent of surface texture, but at the cost of lower resolution [6,7]. Thus, Depth map Up-sampling (DU) is needed in many high quality 3D systems. Another application of DU is to save bandwidth in multi-view video transmission where depth video frames are usually down-sampled prior to encoding [8] and DU techniques are needed in decoder side.

Different up-sampling methods were proposed to enhance the spatial resolution of depth maps [9–11]; however, DU can yield distortions such as ringing artifacts as well as jagged and blurred edges. The DU methods are usually evaluated in terms of bad pixel rate or by 2D Image Quality Metrics (IQMs) while perceptual 3D factors are not taken into account. In spite of the importance of DU in 3D applications, investigation about the effect of DU approaches on 3D perception has been an unexplored issue. In this paper, the degradation effects of different DU methods on

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stereoscopic images are investigated. First, depth maps were up-sampled using different DU approaches and then a subjective test was used to assess the quality of stereoscopic images obtained from the up-sampled depth maps and color images.

Subjective assessment is time-consuming, expensive and sensitive to conditions such as image/video contents and 3D displays [12,13]. Therefore, a reliable objective method is desirable to evaluate the quality faster and free of human interference. Here, in addition to subjective test, a depth quality assessment framework is provided to compare the effect of different DU methods on 3D quality. The proposed framework is able to efficiently predict the quality of stereoscopic images through objective quality evaluation of their up-sampled depth maps.

Recently, there are emerging research works in the field of 3D IQMs which can effectively estimate the quality of 3D images by considering the interaction between two eyes and physiological studies of binocular perception [14]. Chen et al. [15] developed an objective 3D IQM based on the theories of binocular rivalry. Banitalebi-Dehkordi et al. [16] proposed a new 3D metric by taking into account the cyclopean views, contrast sensitivity of HVS system and the disparity of the views. Lin and Wu [17] utilized the binocular integration behaviors to measure the stereoscopic image quality. A 3D IQM was developed in [18] that captured the information from cyclopean view, binocular rivalry, and the scene geometry for quality evaluation.

The aforementioned 3D metrics considered binocular artifacts in quality estimation; however, the intention of this paper is to provide a depth quality assessment framework for stereo images affected by DU artifacts. The distortion from DU methods can be classified as monocular (2D-based) type that is different from binocular distortions. When the degradation in a stereoscopic image is derived from distortion of its 2D components (i.e. depth map and color image), a straightforward way is to estimate the 3D quality by evaluating the 2D components through 2D IQMs [19,20].

Various 2D IQMs can be used to evaluate the quality of up-sampled depth maps, but they may deliver different results. Since the aim is to predict the 3D quality from depth quality assessment, it is required to choose the IQMs that have higher correlation with 3D subjective assessment. For 2D IQM selection, the amount of consistency between depth quality scores obtained from each 2D IQM and 3D subjective assessment is computed through correlation. The metrics with higher correlation are considered to be better for 3D quality prediction.

In order to improve the depth quality assessment framework, a metric fusion method is proposed. Since there is no single metric that significantly outperforms others, a new concept is to combine different metrics [21]. Previous works in the field of metric fusion mainly focused on 2D applications. Here, we evaluate the effectiveness of 2D IQMs fusion to improve 3D quality prediction. The objective results obtained from 2D IQMs are combined using a regression approach to achieve a higher correlation with the subjective test of 3D images. Our experimental results show that the combined metric improves quality evaluation compared to single 2D IQMs.

This paper examines the effect of different DU approaches on 3D perception using subjective and objective methods. A depth quality assessment framework is proposed to objectively predict the quality of stereoscopic images with up-sampled depth maps. Furthermore, the proposed 2D metric fusion method can improve the 3D quality prediction.

The reminder of the paper is organized as follows: Some related works are reviewed in Section 2. Section 3 describes the depth map quality assessment framework that includes 2D metric selection and metric fusion approaches. Information about the data set as well as objective and subjective tests is provided in Section 4. In Section 5, the experimental results are presented. Finally, Section 6 concludes the paper.

2. Related works

Several methods were proposed in previous works that utilized 2D metrics for 3D quality prediction. In order to choose suitable 2D IQMs, the correlation between the result of each 2D metric and a 3D subjective assessment was obtained in the presence of distortion. Researchers are variant with their opinions of both distortion types and 2D images (depth map or rendered views) based on their 2D IQM selection experiments.

Bosc et al. [20] examined the reliability of 2D image metrics in 3D evaluation by studying the effect of synthesis artifacts on stereoscopic images generated from seven DIBR algorithms. Hewage et al. [22] computed the correlation between subjective and objective assessments on asymmetrically coded stereoscopic videos. The authors evaluated the quality of color images as well as rendered left and right views using Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM) and Video Quality Metric (VQM) [23]. The results showed that VQM outperforms the other two metrics. You et al. [24] applied four distortion types (Gaussian blurring, white noise, JPEG and JPEG2000 compression) to a right view to evaluate the performance of various 2D metrics in 3D quality assessment.

Unlike the aforementioned approaches, another possible method is to include probable depth map artifacts since the quality of synthesized views depends on the accuracy of the depth information. Banitalebi-Dehkordi et al. [25] examined the capability of five quality metrics for 3D quality evaluation by comparing the objective scores of distorted depth maps and subjective results in the context of 3D transmission. The depth map artifacts due to compression and packet loss were considered in their experiment. In this work, the effect of DU artifacts on depth maps and 3D image is investigated to select the validated 2D IQMs for 3D evaluation.

In addition to 2D metrics validation, a metric fusion approach is proposed to improve the quality evaluation results. Okarma [26] showed that a combination of metrics achieves a higher correlation with subjective scores compared to a single metric. Further investigations by fusing some different quality metrics and using new combination methods were performed in [27]. Liu et al. [28] examined the validity of metric fusion through analysis of different metric combinations. They divided the distorted images into various groups based on distortion types and observed that a single quality metric cannot work well for all distortion types. According to their analysis, each quality metric is suitable for a number of distortion types; however, none of these methods can perform well for all groups of distortions.

3. Methodology

This section explains the depth map quality assessment framework used for quality prediction of stereoscopic images with up-sampled depth maps.

Table 1
The DU approaches used in the experiment.

BiLinear Up-sampling (BLU) [29]
BiCubic Up-sampling (BCU) [30]
Bilateral Up-sampling (BU) [31]
Joint Bilateral Up-sampling (JBU) [32]
Variance-Based Up-sampling (VBU) [33]
Noise Aware Filter for Depth Up-sampling (NAFDU) [34]
Distance Transform-Based Up-sampling (DTBU) [35]