PERCEPTUAL EVALUATION OF LIGHT FIELD IMAGE

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ABSTRACT

Recently, light field image has attracted wide attention. However, much less work has been conducted on the perceptual evaluation of light field image. In this work, we create the first windowed 5 degree of freedom light field image database (Win5-LID) based on stereoscopic display, which provides windowed 5 DOF experience and all the depth cues of light field image. The database consists of light field images with representative compression and reconstruction artifacts. We assume that the light field quality is not only affected by sub-views quality but also depth cues. Picture quality and overall quality are then evaluated and the results validate our assumption. Finally, the performance of existing image quality metrics is analyzed on our database. The results indicate that the performance of the state-of-the-art image quality metrics remains to be improved.

Index Terms— Light field, Image quality assessment, Degree of Freedom (DOF), Database, Perceptual evaluation.

1. INTRODUCTION

Light field, as a recently emerging media, describes the distribution of light rays in free space. While recording both the direction and intensity information of radiance, it produces a large amount of information redundancy [1]. To mitigate this problem, research works focus on the light field image processing, such as compression and reconstruction (also called angular super-resolution) [1]. However, the results of these tasks do not take the quality of experience (QoE) into consideration. Since the ultimate receiver of visual information is the human visual system (HVS), evaluating the viewing experience of light field image is crucial.

Light field can provide 6 DOF experience with several 3D depth cues. Here, the 6 DOF denotes 3 DOF (i.e. yaw, roll and pitch), forward/backward, left/right and up/down. The 3D depth cues include monocular cue, binocular cue, motion parallax and refocusing. However, obtaining human response to light field image is difficult because that the 6 DOF light field display is still under exploration. And the commercial display still needs about 3-5 years to come into the market [2]. Therefore, in order to analyze the QoE of light field image, firstly, it is necessary to simulate the viewing experience of light field display. Secondly, due to a variety of factors affect the light field viewing experience, multi-dimensional quality evaluation of the light field image is required.

Recently, several works play light filed image by using the available facility. [3] and [4] employ 2D display. However, they suffer from a fatal drawback that the 2D display cannot deliver binocular disparity. Based on 3D display, [5, 6] carried out subjective experiments on 3D display but they only considered the horizontal parallax. In fact, they can hardly simulate the real light field experience because of lacking in providing refocusing cue and only provide 4 DOF (i.e 3 DOF and left/right) experience.

Since the light field displays are not available, few subjective databases have been built. Most existing databases only consider the applications of light field image without providing annotated subjective scores. For example, LCAV-31 [7], GUC [8], 4D Light Field Database [9] and LFSD [10] focus on specific applications, such as depth map estimation and object recognition. Several released general databases [11, 12] also do not consider perceptual evaluation. Obviously, they are insufficient to deal with the challenge of perceptual evaluation for light field images. For existing subjective databases, [5] provides 3 consecutive horizontal parallax scenes and [6] contains complex scenes with dense horizontal parallax. However, both of them only can provide 4 DOF (i.e. 3 DOF and left/right) as well as ignore the vertical parallax and refocusing. In addition, they didn't analyze the effect of the properties of light field image and only deliver a global quality score.

In order to address the aforementioned problems systematically, we create a windowed 5 DOF (i.e. 3 DOF, left/right and up/down) light field image database based on stereoscopic display, which can provide all the depth cues and an experience closest to that with a real light field display. The database contains representative compression and reconstruction artifacts. Then the subjective experiment is conducted using the double-stimulus continuous quality scale (DSCQS) method. Since the light field image consists of an array of views, the sub-views quality and the inherent properties (i.e. motion parallax and refocusing) should affect the light field image quality. Considering the influence of these factors on light field image quality, two perceptual quality dimensions are evaluated, namely picture quality and overall quality. The results indicate the picture quality cannot represent the overall

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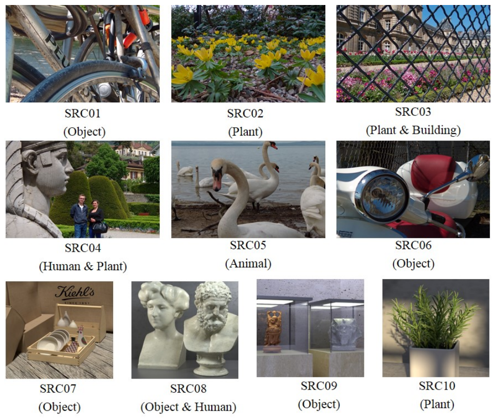


Fig. 1. Illustration of the center view for the selected image contents of source sequences (SRCs).

quality and the inherent properties of light field also have an important impact on the light field image quality. To the best of our knowledge, our work establishes the first windowed 5 DOF light field subjective database based on 3D display and provides both the picture quality and overall quality of light field image.

In addition to subjective assessment, many algorithms have been proposed to predict the perceptual quality of various traditional contents. However, there is no specific objective model for evaluating the quality of light field image. Based on our database, we evaluate the performance of existing state-of-the-art image quality metrics. Specifically, we measure 19 existing full-reference and no-reference image quality assessment metrics. Experimental results demonstrate that the existing metrics are only moderately correlated with the subjective quality ratings.

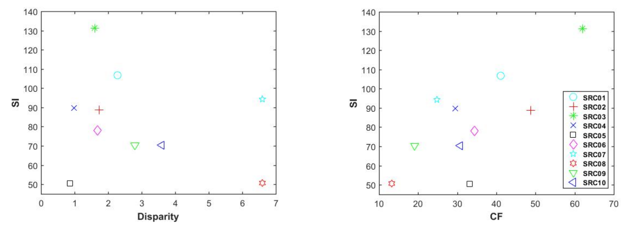
The remainder of the paper is organized as follows. Section 2 describes the proposed Win5-LID in detail. In Section 3, we analyze the database. Then, we evaluate the existing metrics in Section 4. Finally, Section 5 concludes the paper.

2. WINDOWED 5 DOF LIGHT FIELD IMAGE DATABASE (WIN5-LID)

To build the Win5-LID, we select 10 light field images from EPFL [11] and 4D Light Field Databases [9] that includes various characteristics. We introduce typical compression and reconstruction artifacts into the original contents.

2.1. Selection of Contents and Distortions

The choice of source sequences (SRCs) plays a fundamental role in building database. In this work, we consider the low-level features (i.e. disparity range (DR), spatial information (SI) and colorfulness (CF)) as well as high semantic features of the light filed image. Here SI describes scene details and CF has a significant impact on the perceptual quality of the scene. DR represents scene change range. To guarantee the universality of Win5-LID, the selected SRCs should cover a wide range of content features. Specifically, we select 6 real scenes (SRC01−SRC06) captured by Lytro illum [11] and 4 synthetic scenes (SRC07−SRC10) [9] as pristine images. The selected image contents of SRCs are shown in Fig. 1. The disparity, SI, and CF of these images are then computed and shown in Fig. 2. From Fig. 2, we can see that the selected contents cover a wide range of key low attributes and contain abundant semantic features, such as human, plant, animal, and object. All contents are of identical angular resolution 9×9. The spatial resolutions of real scenes and synthetic scene are 434×625 and 512×512, respectively.



(a) (b)

Fig. 2. (a) Distribution of SI and DR. (b) Distribution of SI and CF.

In Win5-LID, we consider two types of representative artifacts, the compression and reconstruction distortions. For each type of distortions, we introduce artifacts with different severity levels to explore the visual experience of light field in varying levels of distortion. As a result, we design 22 Hypothetic Reference Circuits (HRCs), which are listed in Table 1. Finally, the created Win5-LID contains 220 processing images. We then present each type of introduced distortions as follows.

Compression: To transmit light field data, efficient compression algorithms are necessary. However, the compression standards for light field image are under development [13]. The existing compression schemes are mainly based on JPEG2000 and HEVC encoders [1, 14], so the type of distortion remains unchanged. In our experiment, we introduce the JPEG2000 and HEVC artifacts. For JPEG2000, we compress light field image based on lenslet and set the compression ratio (CR) to {25, 50, 100, 150, 200}. The HEVC codec encodes light field image through a pseudo-video sequence, which is generated in a serpentine manner. Quantization steps (QP) are set to {24, 29, 34, 39, 44}.

Reconstruction: Spatial and angular resolution trade-offs is an inherent problem for light field capturing [1]. Many research works have paid much attention to light field reconstruction to solve this problem [1]. However, it is inevitable to introduce this type of distortion during the processing. In this work, we choose four different reconstruction algorithms

Table 1. Hypothetic Reference Circuits (HRCs).

HRC-ID	Process Method	Parameters	Distortion Level
HRC01	HEVC	QP=24	Level1
HRC02	HEVC	QP=29	Level2
HRC03	HEVC	QP=34	Level3
HRC04	HEVC	QP=39	Level4
HRC05	HEVC	QP=44	Level5
HRC06	JPEG2000	CR=25	Level1
HRC07	JPEG2000	CR=50	Level2
HRC08	JPEG2000	CR=100	Level3
HRC09	JPEG2000	CR=150	Level4
HRC10	JPEG2000	CR=200	Level5
HRC11	Linear Interpolation	K=10	Level1
HRC12	Linear Interpolation	K=20	Level2
HRC13	Linear Interpolation	K=30	Level3
HRC14	Linear Interpolation	K=40	Level4
HRC15	Linear Interpolation	K=50	Level5
HRC16	Nearest Interpolation	K=10	Level1
HRC17	Nearest Interpolation	K=20	Level2
HRC18	Nearest Interpolation	K=30	Level3
HRC19	Nearest Interpolation	K=40	Level4
HRC20	Nearest Interpolation	K=50	Level5
HRC21	[15] model	DEFAULT	-
HRC22	[16] model	DEFAULT	-

to process the pristine images, including linear interpolation, nearest neighbor interpolation, and two state-of-the-art models. The first two methods are parameterized by sub-sampling rate K in the angular domain. The values of K are select as $\{10, 20, 30, 40, 50\}$. Two state-of-the-art CNN models, [15] and [16] are also adopted by our Win5-LID. These models all run with the default parameters.

2.2. Subjective Experiment

In our experiment, in order to provide all depth cues of light field image, we extend DSCQS evaluation method and implement an interactive experimental mode. Participants can change the perspective by pressing the mouse and dragging. Also, when clicking on the image, the corresponding refocusing results can be obtained. All participants are informed that the right side of the screen is the reference image. Meanwhile, they are instructed that picture quality refers the perceived quality of sub-views and overall quality refers to the whole quality of the light field image provided by the system. Also, the overall quality is affected by the picture quality and the inherent properties of light field. The scores are measured on 5 discrete scales with 1 for very annoying and 5 for imperceptible.

The stimulus order is random for all participants to eliminate the effect of potential bias. Horizontally adjacent views of light field image as left and right view separately, the binocular disparity is within $\pm 0.1°$ [17] to guarantee a comfortable viewing.

The experiment environment conforms to the ITU standard [18] and ensures that the results are reproducible. The stereo display is 55-inches SAMSUNG UA55HU8500J 3D television with shuttle glass, whose resolution is 1920×1080. The region outside the image is filled with black. Recommended by ITU standard, viewing distance is set to 1.2m [18].

29 non-expert participants take part in the subjective experiment, whose age is from 19 to 26. The average age is 22.69. All participants have a normal vision acuity or corrected-to-normal acuity and for normal colour vision. Before starting the experiment, there is an instruction and training phase to make each participant get familiar with the test and establish stable assessment criteria. Each image can be watched for the unlimited time. Total experiment time is approximately 90 minutes. Each session lasts 25 minutes and participants need to rest 5 minutes for every session to minimize the effect of visual fatigue.

3. ANALYSIS OF SUBJECTIVE DATABASE

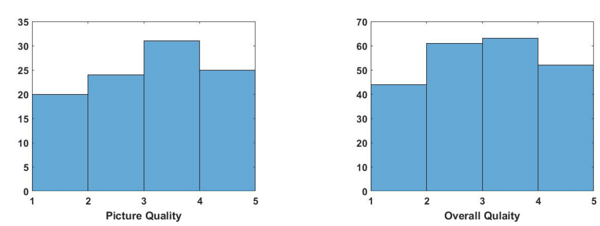
To ascertain the distribution of scores is normal, we remove the participant whose correlation with average image quality is lower than 0.75 or with average overall quality below 0.8. Then 23 valid participants (9 females and 14 males) are obtained. The mean opinions scores (MOS) is obtained by averaging the score of all participants. In the following, distribution of MOS and influence of HRCs are analyzed.

3.1. Distribution of MOS

According to ITU [35], we adopt the 95% confidence interval (CI95) to denote that the difference between the experimental mean score and the true mean score (for a very high number of participants) is smaller than the CI95 with a probability of 95%. In our experiment, the average CI95 values of image quality and overall quality are 0.30 and 0.34, respectively. This result indicates that all the participants reach a reasonable agreement on the perceived quality of images. The MOS value can be regarded as the ground truth.

To analyze the distribution of Win5-LID, we compute the distribution of MOS. Due to reconstruction distortion has little effect on the picture quality and delivers good quality (MOS$\geq$3.5), we do not consider it for the picture quality condition of reconstruction sequences. Histogram of picture quality of compressed sequences and overall quality of all sequences are shown in Fig.3. Obviously, all scores are approximately uniformly distributed in various intervals. It demonstrates that the Win5-LID is well-distinguished and evenly distributed.

3.2. Perceived Results Analysis



(a) (b)

Fig. 3. (a) Distribution of picture quality of compressed sequences.(b) Distribution of overall quality of all sequences.

Table 2. Performance of the objective image quality metrics on our database.

		Picture Quality				Overall Quality			
Type	**Metrics**	**SROCC**	**PLCC**	**KROCC**	**RMSE**	**SROCC**	**PLCC**	**KROCC**	**RMSE**
2D-FR	**PSNR**	0.7701	0.7501	0.5918	0.6949	0.6026	0.6189	0.4469	0.8031
	SSIM [19]	0.7476	0.7844	0.5703	0.6517	0.7346	0.7596	0.5557	0.6650
	VIF [20]	0.8248	0.8804	0.6568	0.4984	0.6665	0.7032	0.4962	0.7270
	VIFP [20]	0.8125	0.8447	0.6376	0.5624	0.6164	0.6795	0.4592	0.7502
	FSIM [21]	0.6874	0.7475	0.5224	0.6979	0.8233	0.8318	0.6497	0.5675
	MS-SSIM [22]	0.6854	0.7370	0.5220	0.7102	0.8266	0.8388	0.6481	0.5566
	IW-SSIM [23]	0.6774	0.7255	0.5201	0.7231	**0.8352**	**0.8435**	**0.6542**	**0.5492**
	IW-PSNR [23]	0.7649	0.7200	0.5894	0.7292	0.5369	0.5497	0.3918	0.8542
	VSNR [24]	0.7011	0.7289	0.53340	0.7194	0.3961	0.5050	0.2896	0.8826
	UQI [25]	0.7680	0.8207	0.5861	0.6004	0.6333	0.6819	0.4628	0.7479
	IFC [26]	0.8162	0.7089	0.6503	0.7411	0.5028	0.5393	0.3664	0.8611
	NQM [27]	0.7069	0.7466	0.5333	0.6990	0.6508	0.6940	0.4839	0.7362
	WSNR [28]	0.7056	0.7033	0.5228	0.7470	0.6528	0.6709	0.4857	0.7583
2D-NR	**NIQE [29]**	0.3347	0.3685	0.2317	0.9785	0.2086	0.2645	0.1404	0.9861
	BRISQUE [30]	0.8483	0.9060	0.6710	0.4523	0.6715	0.7218	0.5114	0.7526
	NFERM [31]	0.8221	0.8839	0.6396	0.5038	0.6219	0.6517	0.4511	0.8167
3D-FR	**Chen [32]**	0.7694	0.7779	0.6005	0.6603	0.5269	0.6070	0.3903	0.8126
3D-NR	**BSVQE [33]**	0.8261	0.9027	0.6610	0.4711	0.8160	0.8200	0.6327	0.6033
	SINQ [34]	**0.8890**	**0.9314**	**0.7364**	**0.3922**	0.7827	0.8056	0.6118	0.6227

As shown in Fig. 4, to study the influence of HRCs, MOS across all contents for each HRC is averaged and the error bar represents the standard deviation.

Obviously, the picture quality is always better than the overall quality, which validates picture quality cannot represent the quality of light field image. A potential reason is that participants tend to reserve some margin for consideration inherent properties of the light field. Meanwhile, picture quality declines while the overall quality is dropping off, especially from HRC01 to HRC10. The correlation coefficient between picture quality and overall quality can reach 0.76. It indicates picture quality has a significant impact on the overall quality, but it is far from the only factor.

Although reconstruction distortion delivers high score in picture quality, serious reconstruction distortion still leads to low overall quality (HRC11−HRC20). This is because the reconstruction distortion can destroy the motion parallax, and produce a noticeable 'frozen' phenomenon. It verifies the inherent properties of light field image also have an important influence on the overall quality. For two CNN models, [15] and [16] (HRC21 and HRC22) have good picture quality but worse overall quality. Since these show poor performance for large DR contents, especially for SRC07 and SRC08. It demonstrates the existing models still need improvement.

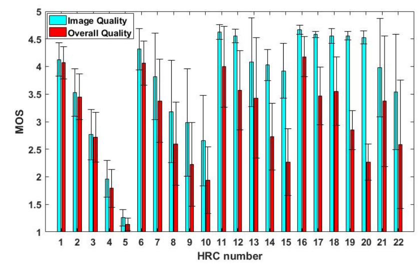


Fig. 4. Picture quality and overall quality of all HRCs.

4. PERFORMANCE EVALUATION OF EXISTING OBJECTIVE METRICS

We consider 19 popular image quality assessment metrics and evaluate their performance on Win5-LID. TABLE 2 shows all metrics. Here we implement PSNR and SSIM [19] with the MATLAB API. The VSNR [24], UQI [25], IFC [26], NQM [27] and WSNR [28] are implemented by the source code from [36]. Remaining algorithms softwares are provided by the authors. All the algorithms run with the default parameters. Each view is computed separately and we get the final score by averaging all views. Correlation between MOS and predicted results is computing by using SROCC, PLCC, KROCC, and RMSE. The SROCC and KROCC measure the monotonicity while PLCC evaluates the linear relationship between predicted score and MOS. The RMSE provides a measure of the prediction accuracy. The value of SROCC, PCC and KROCC closing to 1 represent high positive correlation and a lower RMSE value indicates a better performance.

The performance of the objective algorithms is shown in TABLE 2. Note that the best results are in bold font. For picture quality, SINQ [34] outperforms other FR-IQA metrics and IW-SSIM [23] provides the best results on the overall quality. However, there is a gap between existing metrics and subjective quality rating. Since all algorithms do not consider the intrinsic properties of the light field image, especially motion parallax and refocusing. Specifically designed model for light field image quality assessment is required.

5. CONCLUSION

In this paper, we build Win5-LID based on stereoscopic display, which provides windowed 5 DOF experience and all depth cues of light field. The database considers the perceived quality of representative compression and reconstruction artifacts. The relationship between picture quality and overall quality of the light field images is investigated. We also evaluate the performance of existing objective metrics for light field image. The results show that a new light field specific objective model is required. However, there are still some typical distortions of light filed image and we'll research in the future. Meanwhile, we will make our database publicly available and focus on building a new objective model.

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