Objective Evaluation Criteria for Stereo Camera Shooting Quality under Different Shooting Parameters and Shooting Distances

Jiachen Yang, Yun Liu, Qinggang Meng, and Rongrong Chu

***Abstract*—The vigorous development of three-dimensional (3D) technology has improved the photography technology of stereo cameras constantly. However, there are no widely recognized objective evaluation criteria for stereo camera shooting quality under different shooting parameters and shooting distances. At the same time, no shooting guideline can be used for reference when people take stereoscopic images. To solve this problem, we propose the objective evaluation criteria of shooting quality of two types of stereo cameras (parallel and toed-in camera configurations) under three shooting conditions (macro shooting, short and long distance shooting). In our work, several prominent evaluation factors are built by analyzing the characteristics of each shooting condition. Based on the effective five-point scale used in our subjective experiments, the relationships between shooting factors and shooting quality are obtained and then effectively integrated together to build the overall evaluation criteria. Finally, extensive experiments have been conducted, and the results demonstrate that the proposed approach can effectively evaluate the shooting quality of stereo cameras.**

***Index Terms*—Stereo cameras, objective evaluation, shooting principles, stereo images, parallel and toed-in camera configuration, stereo shooting.**

I. Introduction

WITH the development of 3D technology [1]-[4], stereo image sources are increasing around the world, which allows people to see the stereo images on the screen. However, some stereo image sources suffer from various kinds of distortions which may cause visual discomforts like dizziness, nausea, and the declining of the body balance. Normally, the obtained 3D images are thought to have ideal quality, while the improper parameter settings during the source image capturing process may cause uncomfortable stereo effect. It is important to identify the reasons of quality degradations to maintain the required quality of stereo contents. People usually attributes these visual discomforts to the lack of the stereo image processing and display technology, thus a number of efficient perceptual image quality assessment algorithms, which can be used to estimate the quality of the images with various kinds of distortions, have been presented [5], [6]. However, the evaluation systems still cannot assess all the visual discomforts, and the current evaluation theories mainly focus on the comparison between the stereo images before and after processing.

To address the above issues, several studies have investigated the effect of shooting conditions on the shooting quality [7], [8] which can be categorized into the subjective [9] and objective assessment methods [10]. Since subjective methods are time-consuming and impractical for online applications, objective methods have attracted more attention. A straightforward way is to study the objective perceptual shooting quality criteria by considering the factors of individual stereo cameras [11], [12]. Hasmanda et al. [13] presented a method to calculate the best setting of a pair of stereo camera based on the available camera parameters, e.g. focal length, parallax, inter-camera distance. IJsselsteijn et al. [14] presented a study to investigate the effects of manipulating inter-camera distance, convergence distance and camera focal length on perceived quality and naturalness. However, these methods only focused on studying several shooting parameters and how these parameters affected the shooting quality. Various human perceptions, such as visual fatigue, puppet-theater and cardboard effect and so on, also link to the shooting quality, many camera shooting methods have introduced human visual perception into their models [15]. Kim et al. [16] proposed a visual fatigue metric that could predict the levels of visual fatigue result from stereoscopic images by considering the impact of shooting distance and inter-camera distance. By analyzing the influence of inter-camera distance and camera focal length on cardboard effect, Yamanoue et al. [10] introduced parameter setting principles to achieve good stereoscopic image quality.

The above approaches studied the relationship between the effect of several shooting parameters or human perception and shooting quality, but so far there are still no widely recognized and effective objective evaluation criteria for stereo camera shooting quality. Inspired by the previous studies, we take advantage of individual characteristics of three shooting conditions, and propose the effective evaluation factors. By using the five-point evaluation scale in our subjective experiments, the individual mapping between subjective evaluation and each evaluation factor value is studied first and then the final evaluation criteria by considering the importance of each component are proposed. The main contributions of our

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TABLE I
MEANING OF STEREO CAMERA PARAMETERS

Camera parameters (physical value)	Semantic meaning
h (/mm)	the shooting distance
d (/mm)	the inter-camera distance
f (/mm)	the camera focal length
p (/°)	the viewing angle
m (/mm)	the foreground parallax
n (/mm)	the background parallax
l (/mm)	the scene depth
W (/mm)	the CCD size
L_{min} (/mm)	the distance between the closest scene and the camera center
L_{max} (/mm)	the distance between the farthest scene and the camera center

paper are summarized as follows: (1) By analyzing the related shooting characteristics of two types of stereo cameras, we propose the five-point scale evaluation factors under different shooting distances based on the subjective experiments, and then linearly integrate them together to build the final overall objective shooting quality evaluation criteria of stereo camera. (2) Based on the relationships between shooting quality and stereo camera parameters, extensive subjective experiments have been conducted and the results demonstrate that the proposed criteria can achieve a good consistency with subjective assessment value.

The rest of the paper is organized as follows: Section II introduces the basic shooting principles; Section III describes the proposed objective shooting quality evaluation criteria of stereo camera; Section IV proposes the establishment of shooting principles and evaluations theories; Section V presents the experimental results and analysis; and Section VI concludes the paper.

II. BASIC SHOOTING PRINCIPLES

Stereo shooting is generally divided into two types: parallel and toed-in camera configurations [15], [17]. Hoffman et al., through their experimental analysis of the parallel and toed-in camera configurations, discovered that the short and long shooting distances (the shooting distance is measured from the stereo camera setup to the photographed objects) have different influence on the quality of images captured by stereo cameras [18]. When people watch natural scenes with different shooting distances, the region they are interested in is different. So the information acquired by human eyes is also different [15], [19]. For example, in macro shooting, the attention is focus on the object closest to the cameras, while in short and long distance shooting, the foreground and background as well as the regions of interest should all be considered (in this paper, the foreground refers to the scene in front of the observer's interest regions and the background refers to the scene behind the observer's interest regions). This paper aims to establish the evaluation criteria for parallel and toed-in camera configurations under three different shooting distances: macro, short and long distances. The parameters adopted to establish the objective evaluation criteria are shown in Table I.

The basic shooting principles include the following:

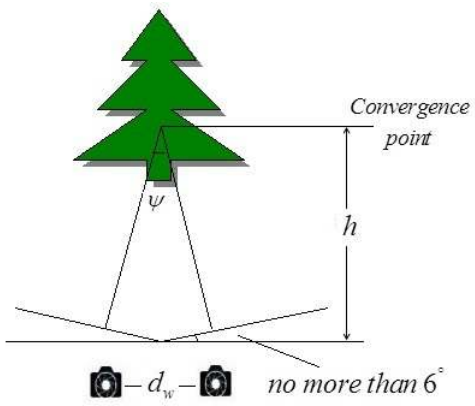

Fig. 1. 12° theory schematic diagram

• 1/30 rule: in professional stereo shooting activities, the 1/30 rule of thumb of 3D [20]-[22], which stipulates that the inter-camera distance should be 1/30 of the distance from the camera to the first foreground object, is widely used in stereo photography.

• 12° theory: for toed-in camera configuration, 12° theory [7] can control the range of inter-camera distance in all scales. The 12° theory means the incline angle of the camera does not exceed 6° in macro shooting, at the same time the convergence angle (ψ) of camera optical axes is not more than 12° (shown in Fig. 1). The theory is shown in Eq. 1.

$$d_w = 2 \cdot h \cdot \tan(\frac{\psi}{2}) \tag{1}$$

where d_w is the theoretical inter-camera distance, h is the shooting distance, $\psi \leq 12°$.

• Ratio of binocular overlap to visual field: the magnification of an image on the retina is BE/CE [13], [15], [23], [24], shown in Fig. 2 (here, BE is the width of captured stereo image [25], CE is the width of composite image, denoting the binocular overlap of stereo camera). The value of BE/CE can affect the values of the positive and the negative parallax and further affect the quality of the stereo images. To simplify the calculation, specify CE/BF as the evaluation index in this paper, where BF is the camera viewing region. The effect of stereo images varies with the change of CE/BF. p is the viewing angle of the stereo camera (as shown in Table I). Based on the geometric relationship in Fig. 2, we make the conclusion present in Eq. 2.

$$\begin{cases} \frac{CE}{BF} = \frac{CE}{BC+CE+EF} \\ BC = EF = d \\ BE = BC + CE \\ h = \frac{BE/2}{\tan(p/2)} \end{cases} \tag{2}$$

• Angular disparity theory: studies about human factors suggested that a certain angular disparity should be maintained in order to generate comfortable images [24]. Previous study indicated that, if the angular disparity ξ equals to $70'$ [8], the better stereo effect can be achieved without visual discomfort. In Fig. 2, α is the angle on the convergent direction, and β

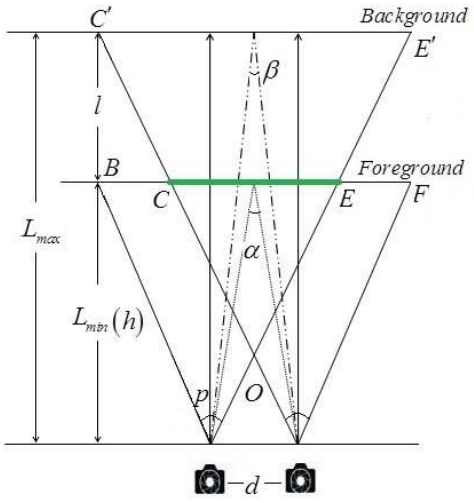

Fig. 2. Binocular overlap and angular disparity schematic diagram for parallel camera configuration

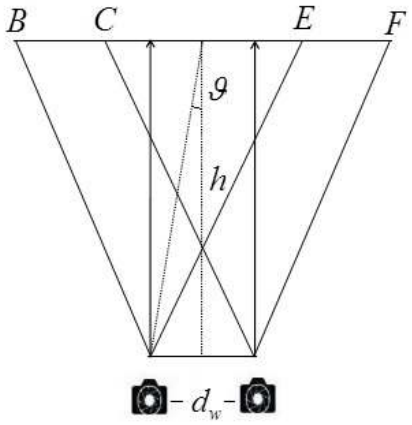

Fig. 3. Visual acuity of camera schematic diagram

is the angle on the divergence direction. The corresponding relationship among α, β and ξ is shown in Eq. 3.

$$\begin{cases} \alpha = 2 \cdot \arctan(\frac{d/2}{L_{min}}) \\ L_{max} = L_{min} + l \\ \beta = 2 \cdot \arctan(\frac{d/2}{L_{max}}) \\ \xi = \alpha - \beta \end{cases} \tag{3}$$

where, d is inter-camera distance, L_{min} is the distance from the closest scene to the camera center, L_{max} is the distance from the farthest scene to the camera center.

• Visual acuity of camera theory: the visual acuity of a camera, ϑ shown in Fig. 3, is widely recognized as 0.5° [26]. If the shooting distance h is known, we can get the theoretical inter-camera distance d_w according to the visual acuity of the camera,

$$d_w = 2 \cdot h \cdot \tan(\vartheta) \tag{4}$$

• Ratio of stereo parallax to image width: previous studies [27] investigated the effect of CCD size W and the width

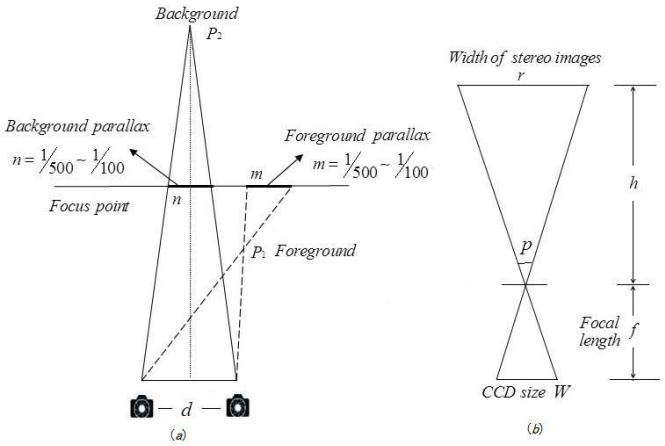

Fig. 4. (a) Foreground and background parallax range schematic diagram; (b) Camera internal structure schematic diagram

of stereo images r on the parallax, they also concluded that the stereoscopic effect of images is better when the range of 3D image parallax within $r/500{-}r/100$ (shown in Fig. 4 (a)) than other conditions. r can be obtained according to the geometric relationship between the parameters in Fig.4 (b), as shown in Eq. 5.

$$\begin{cases} r = \frac{h}{f} \cdot W \\ r = 2 \cdot h \cdot \tan(\frac{p}{2}) \end{cases} \tag{5}$$

The existing shooting principles are simple two-level criteria, which means that the score of shooting quality according to each principle is either good or not, and cannot meet the five-level evaluation demand. Previous proposed stereo shooting principles or models generally take part of influenced factors into consideration or based on human perception, also the shooting principles are two-level evaluation criteria. In 2000, Yamanoue et al. based on a five-point scale of subjective perception, studied the relationship between shooting condition and cardboard effect of stereoscopic images [10]. Later, they used the five-point scale as the evaluation level in the subjective experiment in the work [15], and did the geometrical analysis of puppet-theater and cardboard effects. In this paper, as in [10] and [15], we adopt the five-point scale to instruct the observers to rate the quality of the stereo images from 1 to 5. The proposed five-level subjective evaluation standard for stereo cameras is shown in Table II.

III. Objective Shooting Quality Evaluation Criteria for Stereo Cameras

Based on the previous studies on shooting principles and the characteristics of two types of stereo cameras [16], [17], we analyze two objective evaluation criteria of shooting quality for parallel and toed-in camera configurations, respectively, under three shooting conditions (macro shooting, short and long distance shooting). Then the criteria are integrated into an overall quality index. The frameworks of the proposed criteria are shown in Fig. 5 and Fig. 6.

TABLE II
CRITERIA FOR SUBJECTIVE QUALITY EVALUATION OF STEREO CAMERA

Response	Explanation	Quality
5	**Imperceptible**: there is no any damage on depth perception, and image quality, looks comfortable and natural, suitable for human visual experience.	Excellent
4	**Perceptible but not annoying**: there is a slight loss on depth perception, but the quality of the whole image is still good, suitable for human visual experience.	Good
3	**Slightly annoying**: there is obvious loss on depth perception; however you can accept this quality, reluctantly, generally suitable for human visual experience.	Fair
2	**Annoying**: there is need to carefully distinguish the depth perception not suitable for visual experience.	Poor
1	**Very annoying**: nearly no depth perception, people feel uncomfortable.	Bad

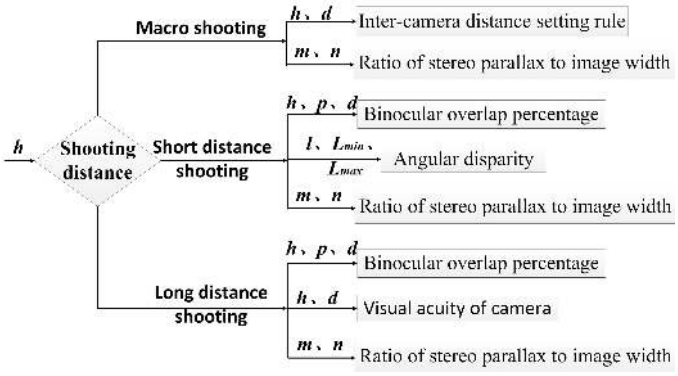

Fig. 5. Objective criterion for shooting quality evaluation of parallel camera configuration

A. Explanation of the Objective Evaluation Criteria

In order to explain the ideas underline the shooting quality evaluation criteria frameworks, we first explain how to build the criteria shown in Fig. 5 and Fig. 6. In 2003, Lao et al. [27] presented that image parallax plays an important role in shooting quality for both parallel and toed-in camera configurations. So we take "Ratio of stereo parallax to image width" as one of the key factors under all the shooting conditions for both types of stereo cameras. What's more, it is worth mentioning that compared with the toed-in camera configuration, parallel camera configuration has an unique and special area called the binocular overlap area, which means: no matter how other shooting parameters change, the inter-camera distance always equal to the horizontal shift between the right and left images. Based on the binocular overlap area, the factor of "Binocular overlap percentage" is applied to the criteria of short and long distance shooting of parallel camera configuration, but not macro shooting condition. Because of the limit shooting distance, the factor of "Binocular overlap percentage" has little effect on the quality of macro shooting condition. Besides, because of the complicated calculating process, "Binocular overlap percentage" is not used to build the criteria of toed-in camera configuration. The specific shooting criteria are explained as follows:

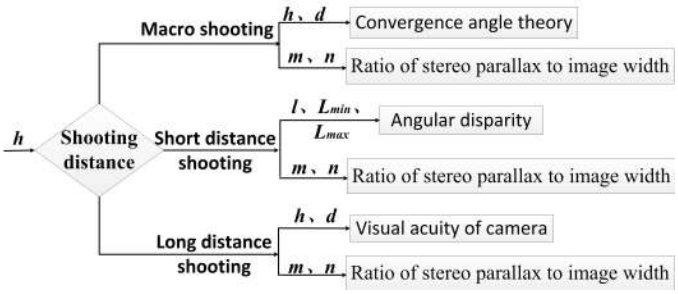

Fig. 6. Objective criterion for shooting quality evaluation of toed-in camera configuration

Parallel camera configuration: the parallel camera configuration converges at infinity and the captured 3D scene appears to be entirely in front of the screen. And each photographed scene is known to have a negative horizontal pixel parallax [28]. **For macro shooting**, because of small shooting area, the foreground parallax is important in the shooting quality. So we add "Inter-camera distance setting rule" [20]-[22] to reflect the effect of foreground parallax. **For short distance shooting**, the scale of shooting scene is bigger than macro shooting, thus "Angular disparity" [8], [24] which determine the whole parallax distribution is selected to evaluate shooting quality. Then "Binocular overlap percentage" is also considered to be one of shooting principles under both short and far distance shooting. **For far distance shooting**, because of the limited visual acuity of stereo camera [26], the background stereo shooting quality is very important. Therefore, in addition to "Binocular overlap percentage" and "Ratio of stereo parallax to image width", we further add "Visual acuity of camera" to establish the parallel shooting criteria.

Toed-in camera configuration: different from parallel camera configuration, toed-in camera configuration converges at a single point and the shooting images obtain the concave-convex feelings [7]. These different structure characteristics lead to different evaluation criteria. **For macro shooting**, the foreground parallax is determined by "Convergence angle theory" which is selected as one shooting criterion. **For short distance shooting**, without the characteristic of "Binocular overlap percentage", we apply "Angular disparity" for short distance shooting quality evaluation criteria. **For far distance shooting**, "Visual acuity of camera" is used for far distance shooting quality evaluation.

In summary, all the corresponding individual influencing factors of each shooting condition and the comparison between the proposed method and the existing methods are shown in Table III.

B. Evaluation Experiments and Establishment for Each Objective Evaluation Criterion

This section aims to introduce the evaluation experiments to obtain the subjective and objective assessment scores, and present individual influencing factors of parallel and toed-in camera configurations, respectively.

TABLE III
COMPONENTS OF PROPOSED CRITERIA IN THIS PAPER INCLUDING ALL THE SHOOTING PRINCIPLES STUDIED IN THE LITERATURE AND THE PROPOSED EVALUATION THEORIES FOR STEREO CAMERA IN THIS PAPER. HERE "EXISTING" MEANS THE PREVIOUS SHOOTING PRINCIPLES IN LITERATURE, AND "PROPOSED" IS THE PROPOSED FIVE-LEVEL EVALUATION CRITERION IN THIS PAPER

Shooting type	Distance	Evaluation factor	Comparison
Parallel camera configuration	Macro shooting	Inter-camera distance setting rule	**Existing**: when d/h=1/30, good stereoscopic effect, [20]-[22] it is a two-level evaluation criterion **Proposed**: with the range of d/h, present a five-level evaluation criterion (Section IV.*A.1*))
		Ratio of stereo parallax to image width	**Existing**: stereoscopic effect of images is good when the range of 3D image parallax was within $r/500$-$r/100$ [27] **Proposed**: named c and c_0 as ratio of total and foreground parallax, respectively, present a five-level evaluation criterion (Section IV.*A.1*))
	Short distance shooting	Binocular overlap percentage	**Existing**: value of BE/CE (Fig. 2), can affect the stereoscopic effect of the captured images [13], [15], [23], [24]) **Proposed**: specify CE/BF as the evaluation index to explore the factor effect rule (Section IV.*A.2*))
		Angular disparity	**Existing**: good stereo effect can be achieved, when ξ equals to $70'$ [24] **Proposed**: establish a five-level evaluation factor ξ, through experiments probe mapping between ξ and MOS value (Section IV.*A.2*))
		Ratio of stereo parallax to image width	Ranges of c and c_0 are similar to those under macro shooting
	Long distance shooting	Binocular overlap percentage	Factor affect rule is same with that under macro shooting
		Visual acuity of camera	**Existing**: it is widely recognized as 0.57° [26], people can get d_w in case of the known h **Proposed**: with range of visual acuity, we establish a five-level evaluation criterion (Section IV.*A.3*))
		Ratio of stereo parallax to image width	Ranges of c and c_0 are similar to those under macro shooting
Toed-in camera configuration	Macro shooting	Convergence angle theory	**Existing**: convergence angle is not more than 12° [7], it is a two-level evaluation criterion **Proposed**: a corresponding five-level convergence angle theory is established for extensive utilization (Section IV.*B.1*))
		Ratio of stereo parallax to image width	Ranges of c and c_0 and those of parallel camera configuration are the same
	Short distance shooting	Angular disparity	Similar to the parallel camera configuration, we will establish a corresponding five-level establish criterion
		Ratio of stereo parallax to image width	Ranges of c and c_0 and those of parallel camera configuration are the same
	Long distance shooting	Visual acuity of camera	Similar to the parallel camera configuration, we will establish a corresponding five-level establish criterion
		Ratio of stereo parallax to image width	Ranges of c and c_0 and those of parallel camera configuration are the same

r: the image width;
ϑ: the visual acuity of camera;
ξ: the index of angular disparity;
k_w: the convergence angle theory;
υ: the total parallax of stereo images;
CE/BF: the index of binocular overlap ratio;
d/h: index of inter-camera distance setting rule;
c_0: the index of ratio between total parallax and image width;
c: the index of ratio between foreground parallax and image width;
k: the index of visual acuity of camera for parallel camera configuration;
k_f: the index of visual acuity of camera for toed-in camera configuration;
Q: the comprehensive objective evaluation criteria.

1) Evaluation experiments:

a) Participants: fifty non-professional adults, age from 21 to 36 and all have normal stereo acuity with binocular vision above 0.8, participate in the subjective assessments. Before the subjective experiments, they are asked to take the binocular visual color test and stereo vision test (by viewing the synoptophore or stereo visual inspection pictures).

b) Apparatus: 3D display is the most common media that people watch stereoscopic image and percept the shooting quality, so the display aspects, e.g. display size, watching condition, should not be overlooked [16]. It is important to acknowledge that the depth perceived in stereoscopic content is strongly linked to the characteristics of 3D display such as the size of the display screen [9], viewing condition and so on. However, it is a big topic if we add all of the factors, so the effect of other parameters on shooting quality will be studied in the future. Here, in order to avoid the effect of viewing condition, the observers in the subjective experiments are all suggested to conduct the experiments at the comfortable viewing range suggested by the instructions of each display

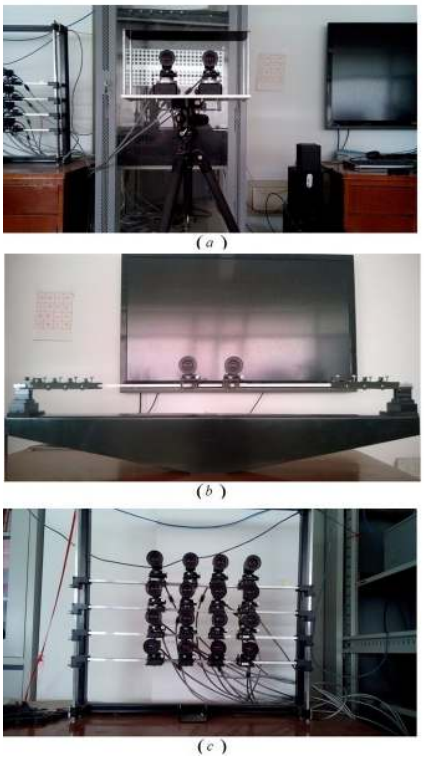

Fig. 7. Real stereo cameras schematic diagram. Sony ICX445 CCD, 1/3″, 3.75 μm; Global Shutter; 1024×768 at 30 FPS. (a) Inter-camera distance can be changed to get macro and short distance shooting images, and also, the parallel and toed-in camera configurations can be obtained; (b) Inter-camera distance can be changed to get macro, short and long distance shooting images, and also the parallel and toed-in camera configurations can be obtained; can get bigger inter-camera distance; (c) Matrix multi-camera arrangement.

device. The subjective tests in this paper are conducted on three different sizes of stereoscopic displays, namely, Philips 423D6W0200 42 inches multi-view auto stereoscopic display, Hyundai S465D 46 inches 3D stereoscopic LCD display and LG 47CM540-CA 47 inches 3D HDTV display. The Philips stereoscopic display can be viewed without glasses and the rest two are paired with their own 3D Active glasses.

c) Source images: double viewpoint images are taken for the subjective experiments. These stereo images are extracted from the stereo image library in the stereo vision laboratory of School of Electronic Information Engineering, Tianjin University, and these images are not selected randomly but according to the stereo scene and shooting parameters. The stereo images in this library are captured by Autodesk 3ds Max and stereo cameras in the laboratory (shown in Fig. 7 (a)-(c)). The size of the training and test stereo images is 1024×768. This database consists of 3636 stereoscopic pairs under various shooting conditions: macro shooting, short distance shooting, and long distance shooting (as shown in Table IV).

d) Procedure: before formal experiments, all participants watch randomly ordered training stereo images for 8 seconds at a viewing distance which is equal to the height of the screen multiplied by factor 3 as suggested in the ITU-R BT.1438 for HDTV [29], then they are asked to evaluate the stereo images with different camera parameters. For example, for the stereo images under macro shooting which are captured with

TABLE IV
NUMBERS OF STEREO IMAGES UNDER VARIOUS SHOOTING CONDITIONS

Type \ Shooting condition	Macro	Short	Long	All
Parallel camera configuration	935	520	365	1820
Toed-in camera configuration	932	520	364	1816
All	1867	1040	729	3636

different camera parameters while the other parameters keep their best value, the observers watch each of the randomly ordered stereo images for 8s followed by a 5s interval, so the subjects have enough time to make the right response and 5s interval can guarantee that each evaluation value is not affected by memory effect [30]. For each of the durations, observers are asked to rate the quality of stereo images using the five-point scale, as shown in Table II. In our experiments, participants are allowed to take a break (e.g. 10 minutes in our experiment) after every 25 minutes quality assessment. The specific time intervals in this paper are determined based on our experience, feedbacks from our pilot studies and previous studies [14][31][32][33]. For the other shooting conditions, we adopt the same procedure above.

The mean opinion score (MOS) [34] is firstly computed for each image by averaging all the subjects' scores, and the Student's t-test [35] is adopted to compute confidence intervals with the significant level being 95%. Then we calculate the range of each influenced factors, and summarize the mapping between each factor and MOS value. The same processes are repeated for the establishment of short and long distance shooting evaluation criteria.

IV. ESTABLISHMENT OF SHOOTING PRINCIPLES AND EVALUATION THEORIES

Based on the shooting principles described in Section II, in this section we extend the existing principles (called "Existing" in Table III) to a five-level criteria (called "Proposed" in Table III) and propose new shooting principles of five-level criteria through experiments. The details of each proposed principle are presented in the following sections.

A. Shooting Principles and Evaluation Theory for Parallel Camera Configuration

Based on the subjective experimental results, we establish the five-level mapping between individual factors and MOS value for each shooting distance, as shown in Table V. The specific experiments conduction and explanations are presented as follows:

1) Macro shooting principles: The evaluation of macro shooting is studied using the inter-camera distance setting rule and the ratio of stereo parallax to image width.

Inter-camera distance setting rule: d/h is specified as the evaluation index of the inter-camera distance setting rule. Based on a series of stereoscopic image pairs and d/h ranges from 1/80 to 1/5, the five-level mapping between the inter-camera distance and MOS value is built through associating subjective experimental results with the range of d/h value shown in Table V. The results indicate that the value 1/30

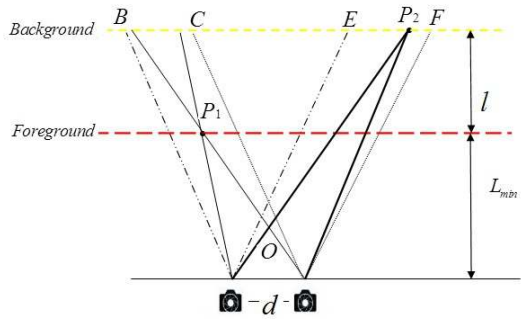

Fig. 8. Total parallax schematic diagram of parallel camera configuration

proposed before [20-22] cannot precisely evaluate the shooting quality, and the specific threshold should be 1/50. To get much better image quality, d/h should be set less than 1/75. Five-level evaluation criterion provides multiple choices to set the shooting parameters d and h, and help people get what they really want (shooting quality ranges from 1 to 5), while the two-level evaluation cannot.

Ratio of stereo parallax to image width: stereo image parallax is an important factor which affects stereo image quality. Although the setting rule of the parallax is already proposed by Lao et al. [27], but it is a two-level evaluation principle, so it cannot be directly used in our criteria. Therefore, a corresponding five-level evaluation criterion needs to be created. This paper takes the ratio of stereo parallax of image width as the final evaluation index to establish the evaluation criteria. For parallel camera configuration (shown in Fig. 8), the stereo images display the shooting scene just like in front of the display screen, the foreground and the background deviate to the same direction. The foreground parallax is greater than the background parallax, so horizontal total parallax of stereo images is the difference between foreground and background parallax [27].

The ratio of total parallax to image width c_0 can be obtained from Eq. 6:

$$\begin{cases} c_0 = \frac{\upsilon}{r} \\ \upsilon = m - n \end{cases} \tag{6}$$

where r is the horizontal width of stereo images, υ is the total parallax of stereo images [27], m is the foreground parallax of stereo images and n is the background parallax of stereo images.

Besides, the foreground parallax has a great effect on the visual comfort and the stereoscopic effect. The ratio of the foreground parallax to image width c (shown in Eq. 7) needs to be taken into consideration.

$$c = \frac{m}{r} \tag{7}$$

In our experiments, a series of different foreground parallax and background parallax are involved. The value of c ranges from 0 to 5.72, and c_0 ranges from 0 to 3.24, the mapping between MOS and c as well as c_0 is further obtained from the experiments as shown in Table V.

2) Short distance shooting principles: The evaluation of stereo camera for short distance shooting is conducted based on the binocular overlap percentage, angular disparity and the ratio of stereo parallax to image width.

Binocular overlap percentage: according to the experiments, we find that the size of the binocular overlap has a certain influence on the stereo image quality. Therefore, this paper establish an evaluation criterion which regards the ratio of binocular overlap to visual field as an evaluation criterion. The individual factor CE/BF is taken as the evaluation index. All test images are divided into several different groups, where the CE/BF value ranges from 0.85 to 0.9985. Through the experiments, we obtain the mapping between CE/BF and MOS value, as shown in Table V.

Angular disparity: in our experiments, a set of stereo images with different angular disparity ξ (shown in Eq. 3), ranges from $0'$ to $91.8'$, are used to establish the five-level evaluation criterion. The mapping between ξ and MOS value indicates that when ξ value is not more than $71.09'$, people can get a good stereoscopic effect. Different from the value of $70'$ in [8], when ξ is set to $71.09'$, people also can obtain the good stereoscopic images. The previous two level evaluation criterion limits the range of shooting parameters and may cause some shooting problems (i.e. increase shooting difficulty and shooting cost).

Ratio of stereo parallax to image width: based on our experimental results, the evaluation mapping is same with that for macro shooting as shown in Table V. With the increasing of c and c_0, the corresponding MOS value is decreasing, the smaller the value of c and c_0, the better the stereoscopic effect.

3) Long distance shooting principles: The evaluation for stereo camera long distance shooting is conducted based on the binocular overlap percentage, visual acuity of camera and influence of the ratio of stereo parallax to image width.

Binocular overlap percentage: it is one of the significant factors which has great effect on long distance shooting quality. The mapping between binocular overlap percentage and MOS value shows that when CE/BF is not more than 0.9596, there is a bit loss on depth perception and this will cause an uncomfortable stereo effect.

Visual acuity of camera: in long distance shooting, the visual acuity of camera is the main factor. Ignoring this factor could result in viewing uncomfortable or even loss of stereo impression. Here let k denotes $\tan(\vartheta)$, the value of k ranges from 0 to 0.05. The mapping between k and MOS value is shown in Table V, the shooting quality will be better when it has a lower k value, no more than 0.013.

Ratio of stereo parallax to image width: through experiments, we find that the evaluation criterion is the same as that of macro and short distance shooting. It indicates that this factor is appropriate for any shooting distance.

B. Shooting Principles and Evaluation Theory for Toed-in Camera Configuration

Like parallel camera configuration, we also summarize the five-level mapping for each case of toed-in camera configuration, as shown in Table VI, which are explained as follows:

TABLE V
MAPPING BETWEEN INDIVIDUAL FACTORS AND MOS VALUE OF PARALLEL CAMERA CONFIGURATION

MOS		5	4	3	2	1
Macro shooting	d/h	$d/h \leq \frac{1}{75}$	$\frac{1}{75} < d/h \leq \frac{1}{50}$	$\frac{1}{50} < d/h \leq \frac{1}{25}$	$\frac{1}{25} < d/h \leq \frac{1}{15}$	$d/h > \frac{1}{15}$
	c	$0 \leq c \leq 2.46$	$2.46 \leq c \leq 2.8$	$2.8 \leq c \leq 3.8$	$3.8 \leq c \leq 4.5$	$c > 4.5$
	c_0	$0 \leq c_0 \leq 0.89$	$0.89 \leq c_0 \leq 0.91$	$0.91 \leq c_0 \leq 2$	$2 \leq c_0 \leq 2.25$	$c_0 > 2.25$
Short distance shooting	CE/BF	$0.9707 \leq CE/BF \leq 0.982$	$0.9649 < CE/BF < 0.9707$ or $CE/BF > 0.982$	$0.9422 < CE/BF \leq 0.9649$	$0.91 < CE/BF \leq 0.9422$	$others$
	ξ	$0' < \xi < 55.85'$	$55.85' \leq \xi < 71.09'$	$71.09' \leq \xi < 79.79'$	$79.79' \leq \xi < 83.79'$	$\xi \geq 83.79'$
	c	$0 \leq c \leq 2.46$	$2.46 \leq c \leq 2.8$	$2.8 \leq c \leq 3.8$	$3.8 \leq c \leq 4.5$	$c > 4.5$
	c_0	$0 \leq c_0 \leq 0.89$	$0.89 \leq c_0 \leq 0.91$	$0.91 \leq c_0 \leq 2$	$2 \leq c_0 \leq 2.25$	$c_0 > 2.25$
Long distance shooting	CE/BF	$0.9676 \leq CE/BF \leq 0.988$	$0.9596 \leq CE/BF < 0.9676$ or $CE/BF > 0.988$	$0.9208 < CE/BF < 0.9596$	$0.9022 < CE/BF \leq 0.9208$	$others$
	k	$k \leq 0.009$	$0.009 < k \leq 0.013$	$0.0013 < k \leq 0.016$	$0.016 < k \leq 0.019$	$k > 0.019$
	c	$0 \leq c \leq 2.46$	$2.46 \leq c \leq 2.8$	$2.8 \leq c \leq 3.8$	$3.8 \leq c \leq 4.5$	$c > 4.5$
	c_0	$0 \leq c_0 \leq 0.89$	$0.89 \leq c_0 \leq 0.91$	$0.91 \leq c_0 \leq 2$	$2 \leq c_0 \leq 2.25$	$c_0 > 2.25$

TABLE VI
MAPPING BETWEEN INDIVIDUAL FACTORS AND MOS VALUE OF TOED-IN CAMERA CONFIGURATION

MOS		5	4	3	2	1
Macro shooting	k_w	$k_w \leq 0.069$	$0.069 < k_w \leq 0.075$	$0.075 < k_w \leq 0.105$	$0.105 < k_w \leq 0.125$	$k_w > 0.125$
	c	$0 \leq c \leq 2.46$	$2.46 \leq c \leq 2.8$	$2.8 \leq c \leq 3.8$	$3.8 \leq c \leq 4.5$	$c > 4.5$
	c_0	$0 \leq c_0 \leq 0.89$	$0.89 \leq c_0 \leq 0.91$	$0.91 \leq c_0 \leq 2$	$2 \leq c_0 \leq 2.25$	$c_0 > 2.25$
Short distance shooting	ξ	$0' < \xi < 55.85'$	$55.85' \leq \xi < 71.09'$	$71.09' \leq \xi < 79.79'$	$79.79' \leq \xi < 83.79'$	$\xi \geq 83.79'$
	c	$0 \leq c \leq 2.46$	$2.46 \leq c \leq 2.8$	$2.8 \leq c \leq 3.8$	$3.8 \leq c \leq 4.5$	$c > 4.5$
	c_0	$0 \leq c_0 \leq 0.89$	$0.89 \leq c_0 \leq 0.91$	$0.91 \leq c_0 \leq 2$	$2 \leq c_0 \leq 2.25$	$c_0 > 2.25$
Long distance shooting	k_f	$0 < k_f \leq 0.03$	$0.03 < k_f \leq 0.05$	$0.05 < k_f \leq 0.06$	$0.06 < k_f \leq 0.07$	$k_f > 0.07$
	c	$0 \leq c \leq 2.46$	$2.46 \leq c \leq 2.8$	$2.8 \leq c \leq 3.8$	$3.8 \leq c \leq 4.5$	$c > 4.5$
	c_0	$0 \leq c_0 \leq 0.89$	$0.89 \leq c_0 \leq 0.91$	$0.91 \leq c_0 \leq 2$	$2 \leq c_0 \leq 2.25$	$c_0 > 2.25$

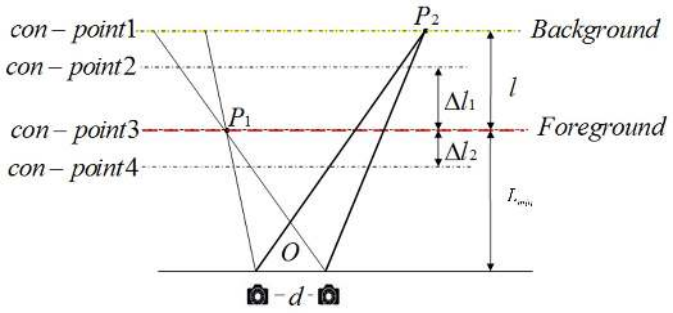

Fig. 9. Total parallax schematic diagram of toed-in camera configuration

1) Macro shooting principles: To derive the evaluation of macro shooting for toed-in camera configuration, the following factors are taken into account: convergence angle theory and the ratio of stereo parallax to image width.

Convergence angle theory: in order to establish the five-level convergence angle theory, here let k_w denotes $\tan(\frac{\psi}{2})$ (ψ shown in Fig. 1), with the value of k_w in our experiments ranges from 0 to 0.3. According to the subjective experiments, mapping between k_w and MOS value is established, which is suitable for evaluating the influence of inter-camera distance on the stereo image quality in the macro shooting of toed-in camera configuration. Based on the previous paper in [7], convergence angle should be set no more than 12°, i.e. k_w should be less than 0.1051. However, our results shown in Table VI indicate that k_w, ranges from 0.075 and 0.105, leads to bad quality of stereoscopic image, and the evaluation rate is 3. The above results indicate that the five-level evaluation criterion is more effective to assess the shooting quality than two level evaluation criterion.

TABLE VII
TOTAL PARALLAX υ OF DIFFERENT CONVERGENCE POINT

The convergence point, shown in Fig. 9	The total parallax υ
On the background, (con-point 1)	$\upsilon = m$
In the middle of a scene, (con-point 2)	$\upsilon = m + n$
On the foreground, (con-point 3)	$\upsilon = n$
In front of the foreground, (con-point 4)	$\upsilon = n - m$

Ratio of stereo parallax to image width: different from parallel camera configuration, here when the position of the convergence point is changed, the total parallax υ of stereo images is different, as shown in Fig. 9 and Table VII, which is analyzed from four aspects based on the location of the convergence point.

c_0 and c can be calculated from Eq. 6 and Eq. 7. Through experiments, series of stereo image pairs are captured with different foreground parallax and background parallax. The value of c ranges from 0 to 5.72, and c_0 ranges from 0 to 3.24. Based on the subjective evaluation experiment results, we obtain the mapping among c, c_0 and MOS value, as shown in Table VI, and it is same with the mapping in macro shooting for parallel camera configuration.

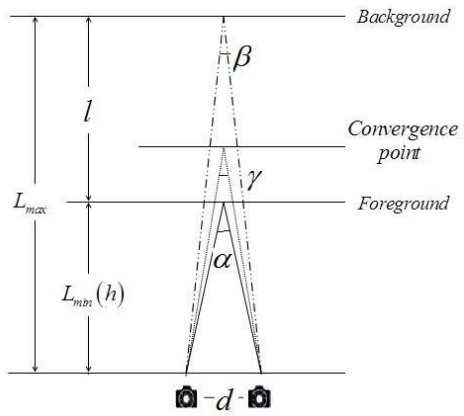

Fig. 10. Angular disparity schematic diagram of toed-in camera configuration

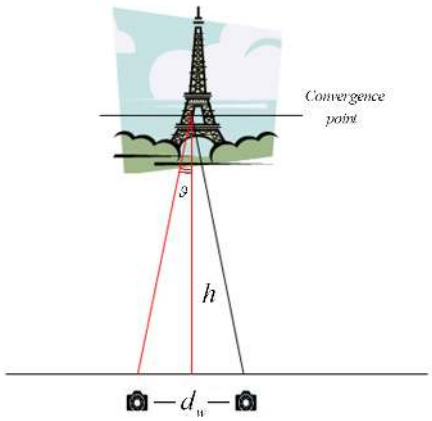

Fig. 11. Visual acuity of camera schematic diagram

2) Short distance shooting principles: The following experiments is conducted.

Angular disparity: the principle of angular disparity is also adapted to the short distance shooting of the toed-in camera configuration, shown in Fig. 10. With a common value of h, another set of stereo images are captured by changing the value of d. α, β and ξ can be obtained according to Eq. 3. Then we change the value of h to get another series of stereo images. The value of angular disparity ξ ranges from $0'$ to $93'$. Subjective experimental results show that the evaluation criterion of toed-in camera configuration is same with that of parallel camera configuration short distance shooting (shown in Table VI).

Ratio of stereo parallax to image width: similar experiments are carried out under the same condition of the macro shooting of parallel camera configuration, we find that the two evaluation criteria are the same for the two camera configurations. With the decreasing of c and c_0 value, people can get a better stereoscopic effect.

3) Long distance shooting principle: In long distance shooting, the evaluation is done from two aspects: visual acuity of camera and the ratio of stereo parallax to image width.

Visual acuity of camera: in long distance shooting, the visual acuity of camera ϑ (as shown in Fig. 11) plays an important role in image quality assessment. To establish a five-level evaluation criteria based on the visual acuity of camera, a series of experiments are done, and the obtained mapping between k_f and MOS value is shown in Table VI. Here specify $\tan(\vartheta)$ as k_f, ranges from 0 to 0.2. The final evaluation factor k_f about visual acuity of camera is presented based on these experimental results.

Ratio of stereo parallax to image width: through the experiment results, the evaluation criterion is same with that in the macro shooting of parallel camera configuration, people can get a better stereoscopic effect when c is not exceed 2.8 and c_0 is not more than 0.91. The above results demonstrate that c and c_0 are not only suit for both stereo camera configurations, but also for any shooting distance.

C. Comprehensive Objective Evaluation Criteria

In the above, we have investigated the effect of individual factor on image quality for two camera configurations and various shooting distances. In the following, the overall objective evaluation criteria will be set up by combining all the individual factors.

1) Quality evaluation criteria:

The most common way to integrate all of the independent individual factor into a global index is the linear weighting method [36]-[38]. In this paper, the specified individual factors in Table VIII are independent from each other, the comprehensive objective evaluation criteria Q can be gained by a linear regression equation of the quality indexes of each factor, which can be defined as

$$Q = u{\cdot}Q_{pi}{+}v{\cdot}Q_{tc}{+}t{\cdot}Q_{pb}{+}w{\cdot}Q_a{+}x{\cdot}Q_v{+}y{\cdot}Q_c{+}z{\cdot}Q_{c0} \quad (8)$$

where u, v, t, w, x, y, and z are the weight values of the five regions in the whole quality, restricted by $u+v+t+w+x+y+z=1$, and all the weight values do not all exist simultaneously.

2) Parameter determination:

To illustrate the process of determination, we take parallel camera configuration macro shooting as an example, Pearson linear correlation coefficient (PLCC) [39] (given by Eq. (9)) is employed to evaluate prediction accuracy. Higher PLCC value indicates good correlation with human subjective judgments.

$$PLCC(MOS,Q) = \frac{\sum_{i=1}^{n}(MOS_i - \bar{MOS_i})(Q_i - \bar{Q_i})}{\sum_{i=1}^{n}(MOS_i - \bar{MOS_i})^2(Q_i - \bar{Q_i})^2} \quad (9)$$

where n is the number of distorted images, MOS_i is the subjective score of the i-th image and Q_i is the objective score of the i-th image, $\bar{MOS_i}$ and $\bar{Q_i}$ are the mean value of subjective and objective score, respectively.

And for the nonlinear regression, we use the following five-parameter logistic function [40]:

$$MOS = \beta_1 \cdot [\frac{1}{2} - \frac{1}{1+exp(\beta_2 \cdot (\chi - \beta_3))}] + \beta_4 \cdot \chi + \beta_5 \quad (10)$$

where β_1, β_2, β_3, β_4, and β_5 are determined by using the subjective scores and objective scores, χ is the subjective

TABLE VIII
MEANING OF INDIVIDUAL FACTORS IN THE QUALITY EVALUATION CRITERIA

Factor	Meaning
Q_{pi}	Output value of inter-camera distance of macro shooting factor for parallel camera configuration
Q_{tc}	Output value of convergence angle theory of macro shooting factor for toed-in camera configuration
Q_{pb}	Output value of binocular overlap percentage factor
Q_a	Output value of angular disparity factor in short distance shooting
Q_v	Output value of visual acuity of camera factor in long distance shooting
Q_c	Output value of ratio of foreground parallax to image width factor
Q_{c0}	Output value of ratio of total parallax to image width factor

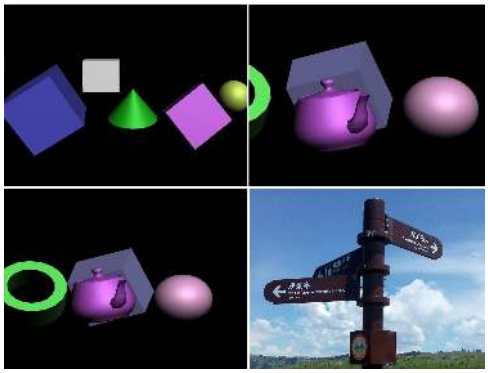

Fig. 12. Left images of four stereo images captured by parallel stereo camera macro shooting

TABLE IX
WEIGHT VALUES OF INDIVIDUAL FACTORS IN OBJECTIVE EVALUATION CRITERIA

Type	u	v	t	i	x	y	z
Macro shooting for parallel camera	0.6	0	0	0	0	0.12	0.28
Macro shooting for toed-in camera	0	0.6	0	0	0	0.12	0.28
Short distance shooting for parallel camera	0	0	0.2	0.35	0	0.2	0.25
Short distance shooting for toed-in camera	0	0	0	0.4	0	0.3	0.3
Long distance shooting for parallel camera	0	0	0.2	0	0.35	0.2	0.25
Long distance shooting for toed-in camera	0	0	0	0	0.4	0.3	0.3

evaluation score of each participant. We select a small set of the stereoscopic images database (four of the left images are shown in Fig. 12) to train the weights u, v, y, and z in Eq. 8 to determine their values by optimizing the PLCC values between the objective and subjective scores. The results are u=v=0.6, y=0.12, and z=0.28. As mentioned above, we can obtain the rest of weight values which are shown in Table IX.

3) Analysis of the proposed criteria:

In order to examine the effect of the above used linear regression and goodness of the fit [41], we adopt three indexes: Sum of Squares Due to Error (SSE) [42], R-Square (R^2) [43], and Root Mean Squared Error (RMSE) [44] (as shown in Eq. 11). Specifically, SSE [42] measures the total deviation of the response values from the fit to the response values, and the value closer to 0 indicates that the criteria has a smaller random error component, and that the fit will be more useful for prediction. R^2 [43] measures how successful the fit is in explaining the variation of the data, and if the fit is worse than just fitting a horizontal line then the value of R^2 is negative. RMSE [44] is known as the fit standard error and the standard error of the regression, and the value closer to 0 indicates a fit that is more useful for prediction.

TABLE X
VALUES OF SSE, R^2 AND RMSE OF EACH SHOOTING CONDITION

Stereo camera	Shooting condition	SSE	R^2	RMSE
Parallel camera configuration	Macro distance	1.198	0.9277	0.33
	Short distance	0.9939	0.9184	0.2041
	Far distance	0.1387	0.9162	0.2151
Toed-in camera configuration	Macro distance	0.9248	0.9207	0.2899
	Short distance	0.6615	0.9554	0.2452
	Far distance	0.1839	0.9186	0.3033

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(MOS_i - Q_i)^2} \tag{11}$$

where n is the number of stereo images, MOS_i is the subjective score of the i-th image and Q_i is the objective score of the i-th image, respectively.

The values of SSE, R^2, and RMSE of each shooting condition and the overall values of the completed dataset are listed in Table X. We can see that the values of R^2 are all higher than 0.91, while the values of RMSE are less than 0.4, and the values of SSE are not big either. The results show that the linear regression method works well and each evaluation metric can contribute to evaluate the shooting quality. The smaller the value of SSE and RMSE, the better of the proposed quality evaluation criteria; the closer the value of R^2 to 1, the better the performance of the metric.

V. EXPERIMENTAL RESULTS

In Section IV, numbers of subjective experiments are used to study the mapping between the individual influencing factors and MOS value, thus we establish the objective evaluation criteria for stereo camera according to these experimental results. To verify the proposed overall objective camera evaluation criteria in Eq. 8, another thirty non-professional adults, age from 20 to 40, participate in the subjective assessment

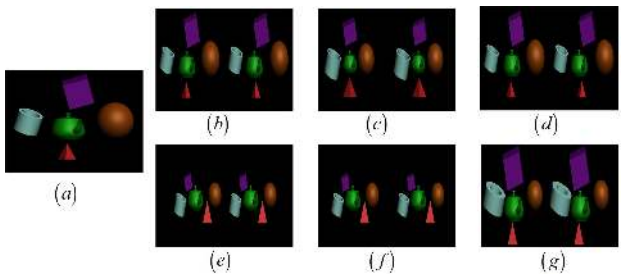

Fig. 13. Stereo image pairs captured by toed-in and parallel camera configurations macro shooting: (a) the selected scene; (b) macro shooting with toed-in camera configuration, d=40 mm, h=600 mm; (c) macro shooting with toed-in camera configuration, d=40 mm, h=900 mm; (d) macro shooting with toed-in camera configuration, d=60 mm, h=600 mm; (e) macro shooting with parallel camera configuration, d=60 mm, h=600 mm; (f) macro shooting with parallel camera configuration, d=12 mm, h=600 mm; (g) macro shooting with parallel camera configuration, d=12 mm, h=950 mm.

experiment. All of them take the binocular visual color test and stereo vision test before the subjective experiments. They are asked to watch the same training images as mentioned in Section III.*B.1*).*d*) and then evaluate the stereo images with different camera parameters. Two hundred and forty test stereo image pairs are used in the subjective experiments and they are displayed in random order.

One of the selected scenes for stereo camera macro shooting is shown in Fig. 13 (a). In the macro shooting of this scene, the stereo image pairs are captured by changing the value of main camera parameters d and h, with the use of the parallel and toed-in camera configurations (Fig. 13 (b)-(d) are the macro shooting of toed-in camera configuration, Fig. 13 (e)-(g) are the macro shooting of parallel camera configuration).

Take the stereo images captured by the toed-in camera configuration as an example, shown in Fig. 13 ((b)-(d)). When d=40 mm, h=600 mm, Q is 4.4. Based on the subjective experiments, the value of MOS [34] is 4.375. As can be seen, the outcome of proposed criteria is congruent with the subjective experiment result. When d=40 mm, h=900 mm, Q is 3.9. Based on fundamental theories of our evaluation criteria, the lager the value h, the smaller the value of the ratio of stereo parallax to image width. The subjective experimental results present that MOS is 3.875. It reveals that our proposed criteria is consistent with the human perception. When d=80 mm, h=600 mm, Q is 2.34. Based on the convergence angle theory, the output value is proportional to the value of h, and inversely proportional to the value of d, thus Q will increase. The result of the subjective experiments shows that MOS is 2.26 and is close to the value obtained from the objective evaluation criteria.

Compared to the toed-in camera configuration shooting situation, stereo images captured by parallel camera configuration are shown in Fig. 13 ((e)−(g)). When d=60 mm, h=600 mm, Q is 1.0 and MOS is 1.50, which is in line with the output of our proposed criteria. When d=12 mm, h=600 mm, Q is 4.6, and MOS is 3.83. The results reveal that the value of d has a great effect on the image quality of macro shooting, which is consistent with our proposed criteria. When d=12 mm, h=950 mm, Q is 5.0. This is because with the increase of foreground and background parallax which is caused by the decrease of d/h value and the increase of h value, the stereo effect of images is further improved. The subjective experimental results show that MOS is 4.6, and close to the value obtained from the objective criteria.

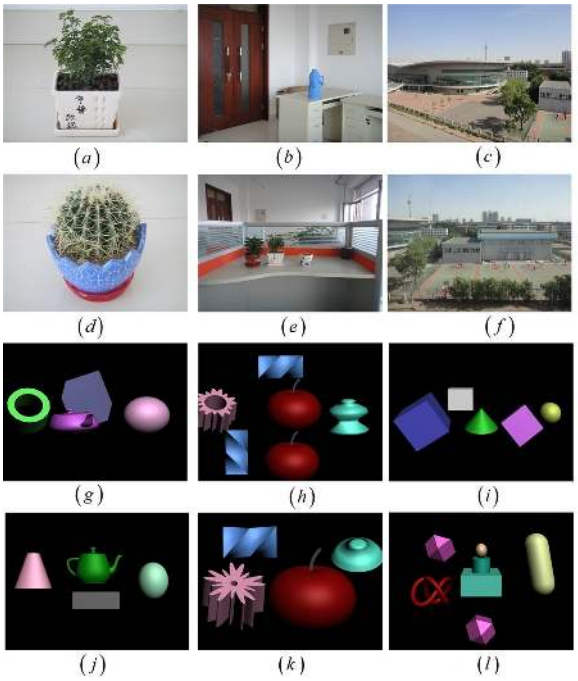

Fig. 14. Left view of stereo image pairs by real camera and 3ds Max: images (a)−(f) are for real camera shooting; images (g)−(l) are for 3ds Max shooting; (a), (g) macro shooting with toed-in camera configuration; (b), (h) short distance shooting with toed-in camera configuration; (c), (i) long distance shooting with toed-in camera configuration; (d), (j) macro shooting with parallel camera configuration; (e), (k) short distance shooting with parallel camera configuration; (f), (l) long distance shooting with parallel camera configuration.

TABLE XI
COMPARISON BETWEEN SUBJECTIVE AND OBJECTIVE EVALUATION

Type \ Index	Parameters in scene	Q	MOS
Short distance shooting with parallel camera	d=65mm,h=4m	3.28	3.0
	d=65mm,h=7m	4.6	3.73
	d=100mm,h=4m	1.0	1.55
Short distance shooting with toed-in camera	d=65mm,h=2.5m	4.8	4.375
	d=100mm,h=2.5m	4.4	4.25
	d=65mm,h=5m	5	4.5
Long distance shooting with parallel camera	d=420mm,h=20m	5.0	4.8
	d=420mm,h=10m	3.4	3.17
	d=6m,h=100m	2.44	2.5
Long distance shooting with toed-in camera	d=9m,h=50m	1.0	1.0
	d=9m,h=100m	4.4	4.75
	d=3m,h=5m	4.3	4.375

The subjective and objective evaluation results in short and long distance shooting are summarized in Table XI, which demonstrate the feasibility of the proposed criteria in this paper.

For ulteriorly verification of the feasibility and validity of the proposed objective criteria in this paper, another twelve groups of experimental scenes are chosen, including the six

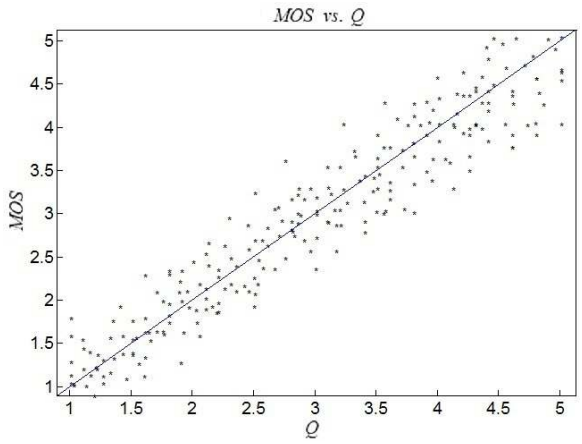

Fig. 15. Correlation between objective and subjective evaluation values schematic diagram

groups of 3D scene pictures (shown in Fig. 14 $(a)-(f)$) of real camera shooting, and the other six groups of 3D scene pictures (shown in Fig. 14 (g)$-(l)$) of Autodesk 3ds Max. By changing the values of shooting parameters h, d, m, n, l and L_{min} of twelve group scenes in the experiment, image pairs are captured for the validity test of the proposed criteria. The linear correlation between the objective evaluation result Q and subjective evaluation result MOS values are shown in Fig. 15. The consistency between the proposed criteria and the subjective evaluation is clearly identified in the figure.

Another four commonly used performance indicators are also employed to further evaluate the proposed metric as suggested by VQEG [39]: Pearson Linear Correlation Coefficients (PLCC), Spearman Rank Order Correlation Coefficient (SROCC), Kendall Rank-Order Correlation Coefficient (KROCC), and RMSE. Among these four indicators, PLCC and RMSE, shown in Eq. 9 and Eq. 11 reflect the predicted accuracy of objective evaluation criteria, and SROCC and KROCC, shown in Eq. 12 and Eq. 13, are used to assess prediction monotonicity [45], [46]. For a perfect match between the objective and subjective scores, the following should keep valid: PLCC=SROCC=KROCC=1 and RMSE=0 [47]. Table XII presents the overall performance of the proposed quality evaluation criteria.

$$SROCC = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n-1)} \tag{12}$$

where n is the number of stereo images, d_i is the different between the i-th image's ranks in the subjective and objective evaluation. KROCC is defined as:

$$KROCC = \frac{n_c - n_d}{0.5n(n-1)} \tag{13}$$

where n_c is the number of concordant pairs in the data set and n_d is the number of discordant pairs in the data set.

What's more, we adopt two index, R^2 [43] and Fleiss' kappa [48], to present the correlation between subjective values and objective values, and measure how successful the fit is in explaining the variation of the data. Here Fleiss' kappa is a statistical measure for assessing the reliability of agreement between a fixed number of participants. Conventionally, a Kappa of < 0.2 is considered poor agreement, 0.21-0.4 fair, 0.41-0.6 moderate, 0.61-0.8 strong, and more than 0.8 near complete agreement [49]. In our paper, R^2 equals to 0.9012 which indicates a good quality, and Fleiss' kappa is 0.79 which indicates the strong agreement.

TABLE XII
OVERALL PERFORMANCE OF THE PROPOSED QUALITY EVALUATION CRITERIA

Index	PLCC	SROCC	KROCC	RMSE
Complete dataset	0.9493	0.9504	0.8036	0.3695

Although we could not compare our work with others as no previous studies have been conducted on shooting quality, however, from the above analysis, we can draw a conclusion that the objective evaluation results of the proposed criteria in this paper are consistent with those of subjective evaluation. With the combination of subjective experiments and theoretical analysis, the proposed criteria are applicable to evaluate the shooting quality of stereo cameras.

VI. CONCLUSION

In this paper, we propose an objective evaluation criteria that can assess the shooting quality of stereo cameras by investigating the relationship between shooting quality and stereo camera parameters. We fully analyze the effect of individual influencing factors on shooting quality by comparing with the results obtained from extensive subjective quality tests. The experimental results show the effectiveness of the proposed quality metric in matching with the subjective ratings. There are two important contributions in this paper. First, the proposed method can be used to guide the 3D photography to capture good quality stereoscopic images. Second, the proposed criteria can also be taken as a rational setting principle of shooting parameters for the amateur. Because the previous studies only take one or a limited number of individual factors into consideration to study their effects on shooting quality, therefore they do not establish the evaluation criteria for stereo camera shooting quality which we can make a comparison with. Further studies will focus on the effect of other parameters, e.g. viewing condition and display size, to establish the comprehensive evaluation criteria with all the shooting parameters.

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