Controlling Depth Perception of Stereoscopic Images under Given Constraints

Tzung-Han Lin

Abstract—**This paper addresses a practical method for controlling depth perception by adjusting stereo camera parameters. We use 3D graphic models and motion capture data to simulate various action scenarios. The goal is to keep an appropriate 3D effect for the interested character who has a specific motion. This method analyses the parallax distribution for every frame, and the temporal change is also considered for smooth transition between successive frames.**

Index Terms—**depth perception, motion capture, stereoscopic images, visual comfort.**

I. Introduction

PRODUCTION of good 3D content is a difficult art that requires a variety of technical, psychological, and creative skills. It has to consider human perception and display capabilities. Recently, stereo camera has become a programmable device, and it is capable of running a specific script for adapting the stereo camera parameters [1]. The programmable stereo device can simultaneously capture scenes and provide disparity information for analysis. Then, stereo camera parameters are adjusted for changing 3D effect in either automatic ways or manual operations. However, the production of quality 3D content is still costly. Capturing dynamic stereo scenes is much difficult, since it involves temporal change. Therefore, the parameter script generator for various action scenarios is getting important.

There are many physical constraints for stereo cameras when people are taking 3D films [2]. Obviously, the position of the stereo camera and the viewing direction are usually controlled by stereographers, and these two parameters become constraints for forming stereoscopic images. It is still difficult for stereographers to handle the rest parameters of the stereo cameras when they are taking 3D films. Besides, the stereo camera parameters can be an unreasonable value. Based on the need, we develop a tool to analyze parallax distributions for preventing viewing discomfort. The parameter scripts will be generated and used again for reproducing the same 3D effect in similar situations.

II. Background

The visual comfort of stereoscopic images is the most critical problem in stereoscopic researches [3]. It regards the conflict between the accommodation and the vergence of human eyes. It usually refers to the subjective sensation. However, there is no standard methodology for the measurement of visual comfort in stereoscopic images. From the recommendation of the International Telecommunications Union (ITU), it only considers the picture and depth quality on subjective methods [4]. Despite that, the limits of visual comfort are suggested as specific disparity ranges in various viewing conditions [5]. The range of the disparity becomes an important paradigm for producing stereoscopic images. Lambooij found that not only the magnitude but also the distribution of disparities affects visual comfort [6]. It can be modeled as a combined effect of screen disparity range with to a lesser extent screen disparity offset, changing screen disparity and lateral motion of which the specific contributions depend on the activity of the scene.

Jones et al. proposed a controllable perceived depth method for generating stereoscopic images from parallel cameras [7]. Their method transforms the scene depth to a specific perceived depth. The depth distortion is also avoided in head tracked displays; Sun and Holliman used a subjective human-based experiment to evaluate different stereoscopic algorithms [8]. The result shows the practical 3D viewing volume differs between individual displays. The comfortable 3D viewing ranges are expanded in viewing dynamic stereoscopic images in comparison to static stereoscopic images.

Quintus and Halle developed a composition tool for creating comfortable stereoscopic images from static 3D digital models [9]. In their work, camera position, camera view angle, projection plane, viewing distance and interaxial distance are considered for adapting a comfortable stereoscopic image. The tool also provides realistic visualization to assist doctors or engineers having better depth judgment in their professional operations.

Pockett and Salmimaa proposed a quality improvement method for user created stereoscopic content [10]. Their method optimizes the disparity range under a parallel camera configuration. As a consequence, a specific disparity range is guaranteed for mobile device displays.

We have tested the 3D effects of different parameters from motion capture data. Then, a simulation system is developed for analysis of the parallax distributions of stereoscopic images. In our work, the parallax distribution is taken as the main factor for quality 3D content. With the simulation system, desired camera parameters can be used for the design of real stereo cameras.

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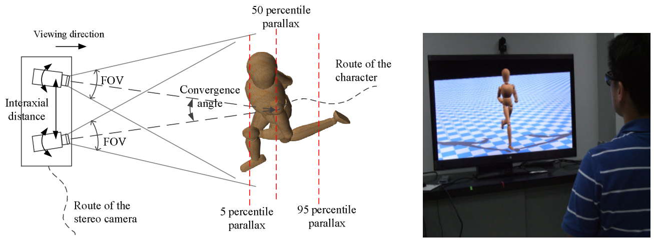

(a) (b)

Fig. 1. Schematics of the virtual stereo camera configuration and the 3D scene on the display. In (a), three parameters in the camera-rig are used for adjusting the 3D effect automatically. The stereoscopic image is synthesized and its parallax distribution is changed to fit the given constraints and specific thresholds shown in (b).

III. Methods

A. Virtual Stereo Camera

In our configuration, the virtual stereo camera system consists of two identical cameras. Their field of view (FOV), convergence angle and interaxial distance are the independent parameters used for adapting the 3D effect as in Fig. 1. Different 3D effects are induced from different parameters, but 3D effects should be acceptable for visual comfort. Although, our method adapts the 3D effect by adjusting stereo parameters, not all parameters produce good 3D content, especially for motion scenes. In most conditions, the stereo camera system has physical limitations. For example, the interaxial distance can't be very small. The convergence angle is very unlikely to be a negative value, since the divergent stereo pairs are very difficult to be fused by human brain.

Fig. 2 illustrates one of the application scenarios. In this scenario, the stereo camera is supposed to follow the path of a running man. Furthermore, a 3D effect with a steady parallax distribution is expected. Base on this requirement, we create a simulation system by openGL to evaluate the 3D stereoscopic effect. The virtual stereo camera and one character with a specific motion are defined. The motion data of the character are from CMU motion capture database [11]. Both views of the stereo camera have the same perspective effect without lens distortion. We do not concern their physical discrepancies, such as color or brightness. All frames are synchronized. And the up vector of the stereo camera should be carefully handled. Our method considers five parameters. They are stereo convergence angle, interaxial distance, field of view (FOV), camera position and viewing direction. All

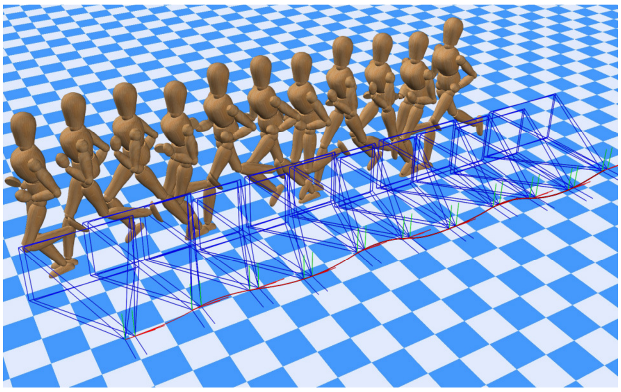

Fig. 2. Schematic of the native constraints in photography: the stereoscopic camera is constrained on a spline path for capturing a running character. Our method dynamically adjusts parameters according to its instant parallax distribution.

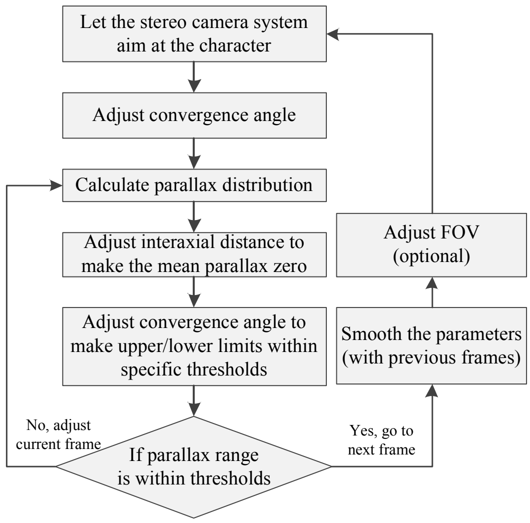

Fig. 3. Flowchart of the proposed method. Our method alternatively adjusts parameters under the given constraints. The FOV is the optional parameter to change the perspective effect.

parameters are either controlled by the stereographer or constrained by our method for rendering different 3D effects.

B. Parallax Analysis

Parallax distribution has become an important feature for assessment of visual comfort in stereoscopic images [12], [13]. The visual comfort regards not only parallax magnitudes but also parallax dispersions. In dynamic stereoscopic scenes, the changing disparity will affect the visual comfort obviously [14]. However, the stereoscopic image needs stereo matching algorithms to have disparity maps. For convenience, we use 3D computer graphics simulation for generating disparity maps. Since the simulated scenes are computer generated, it is easy to acquire binocular depth buffer for analysis in real-time. The parallax data from one stereoscopic frame are converted into a distribution histogram, and only the pixels of the character are considered. In the histogram, we calculate the distribution centroid as the mean parallax. The near limit and far limit of the visual comfort are considered as the 5 percentile and 95 percentile in the parallax cumulative histogram, respectively.

C. Parallax Adjustment

Our method alternatively adjusts the convergence angle and the interaxial distance for changing parallax distribution under the given constraints. Fig. 3 shows the flowchart of our method. Initially, a character motion and stereo camera positions are given. Then, our method adjusts the viewing direction and parameters according to the current status. Since we can't expect where the stereo camera is, these adjustments for stereo camera parameters highly depend on their initial conditions. However, the parallax distribution is calculated from the stereo image. The way we change its distribution is to adjust the interaxial distance and the convergence angle. A larger interaxial distance induces a more hyper stereo effect, and it depends on how far the character is. Our goal is to keep the mean parallax zero in the first iteration. And then, the adjustment of the convergence angle will enlarge or suppress the parallax range. To avoid visual discomfort, we usually set a threshold for the parallax range. For an exaggerating 3D effect, the parallax range is often larger than 1 degree.

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D. Limitation of Method

In many films, the character in specific actions always attracts the audiences. So, we assume that audiences frequently focus their looks at the single character in the central area of the 3D display. To put the character on the center area of the 3D display, the viewing direction is restricted to pass through the locus of the character's bounding box. However, it may make the video jagging. We apply a smooth operation on all the parameters to suppress the jagging phenomenon. It can be done by Kalman filter algorithm, as well. Our method only considers parallax distribution of the character. The result will depend on the distance between the stereo camera and the character. The limitation of our method is that the motion of character and the route of the camera should be continuous.

IV. Result and Discussion

Our experiment device is a 27" polarized stereoscopic display. The developed program is built for generating stereoscopic images from motion capture data. The disparities of stereoscopic images are calculated from the depth buffers of left view images. Then, the parallaxes are converted from the disparities according to the viewing condition. We assume the viewing distance is 90 cm and the pupillary distance is 6.5 cm. In our experiment, the virtual stereo camera generates 60 stereoscopic images per second, and the resolution is 1920 by 1080. The example in Fig. 4 shows the parallax distribution of a kicking character before adjustment. In its parallax distribution, the mean value is used for changing the interaxial distance at first iteration, and then the parallax range is used for adjusting convergence angle, alternatively. The near limit and far limit are at the 5 percentile and 95 percentile of cumulative probability density, respectively. Then, the parallax range of one stereoscopic image is obtained.

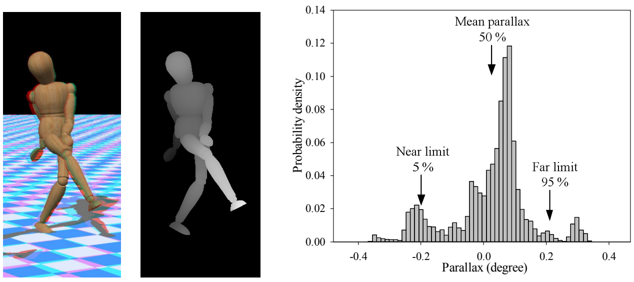
In Fig. 5 and Fig. 6, two different initial conditions with the same motion are shown. In Fig. 5, a small interaxial distance is given for a weak 3D effect initially. To keep the approximate parallax range compared with the first frame, two parameters plotted in Fig. 5(b) are adjusted according to parallax distributions. Due to the geometric relation, we simultaneously adjust these two parameters. Consequently, their variations are reduced. If one of the two parameters has a physical limit, the other parameter still remains one degree of freedom for adjustment. Our method keeps the zero-parallax plane on the centroid of the parallax distribution as possible. Nevertheless, changing the interaxial distance is not the only way for adjusting the value of the mean parallax. For traditional parallel stereo cameras, shifting both images inward or outward is often used for reproducing its parallax distribution. This skill will affect the position of zero parallax only. And it may induce blank pixels on the left and right borders. For the case of a large initial interaxial distance, the similar result is shown in Fig. 6 (b).

Fig. 7 shows the character is walking to the stereo camera whose position is fixed. The FOV parameter is independent and optional. It is used for changing the perspective effect. In this figure, FOV is defined as the function of the character's size, and that will make its size consistent. When the character comes close to the camera, its parallax range is almost the same compared with the initial value.

The camera position is often handled by the stereographer, either along a pre-defined path or on arbitrary routes. Since the stereo camera has six degrees of freedom in Euclidean space, we keep its roll angle constant to avoid unnatural images. In a real case, the pose of the camera can be readily detected by a gyro for compensation. This is a basic requirement in our test system. In Fig. 8, we simulate 3D effects with the stereo camera on a spiral path. The camera moves from top to bottom and always aims at the boxing character. When the camera moves, the camera's pose will be corrected. Then, the stereo camera parameters are updated.

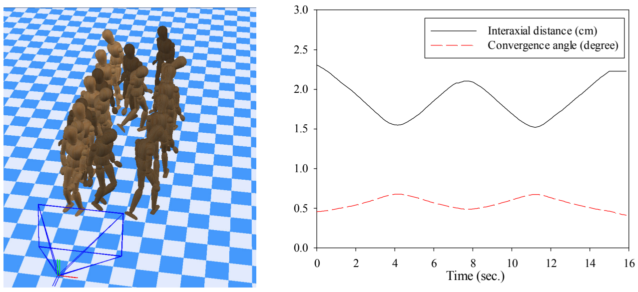
Another example shown in Fig. 9 is a dancing character with a stereo camera on a circular path. In this example, the viewing direction is calculated to focus on the smooth path of this character.

Although our method keeps the mean parallax zero and makes the parallax range controllable, the 3D effect is sometime subjective. It is worth to generate parameter scripts for various kinds of scenarios, since the simulation data provide different experiences for capturing common motions as stereoscopic films. The same scenario frequently happens



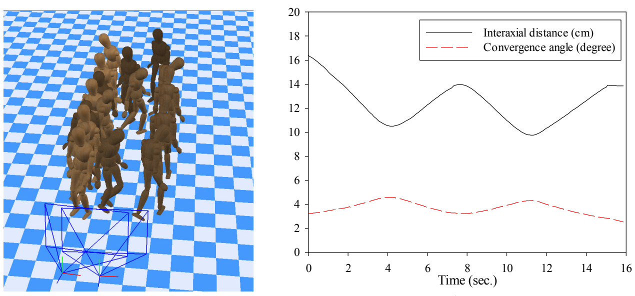
(a) (b) (c)

Fig. 4. Parallax analysis. In (a), a cropped snapshot of the character is shown in anaglyph. Only the depth buffer of the character is considered for analysis in (b). Its parallax distribution is converted from the depth buffer according to the viewing condition in (c).



(a) (b)

Fig. 5. A walk motion and a fixed camera position are shown in (a). Initially, the interaxial distance is small. A man walked twice forward and then backward. The brighter shaded model is at the later position. All generated parameters are plotted in (b).



(a) (b)

Fig. 6. A large interaxial distance is given initially shown in (a). The parameter output is plotted in (b).

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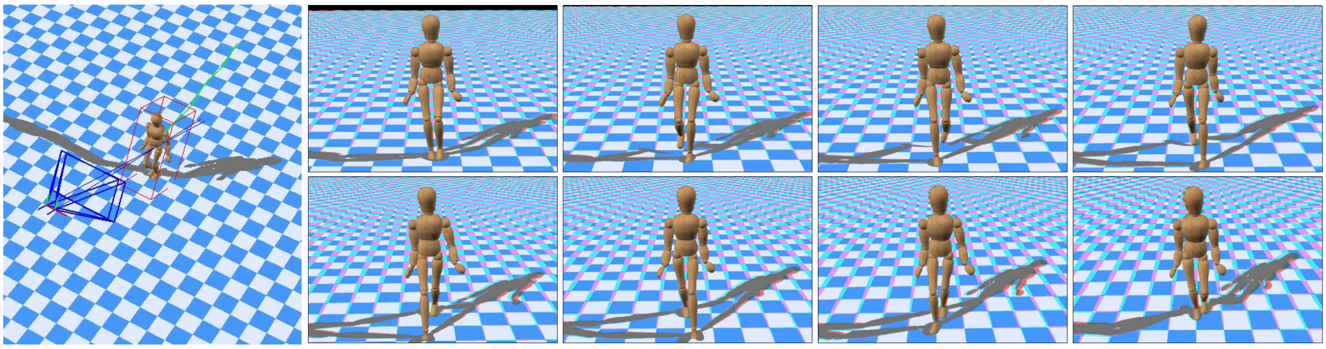

Fig. 7. The character walks forward and the stereo camera position is fixed (left figure). The images with the same parallax range are generated (rest figures).

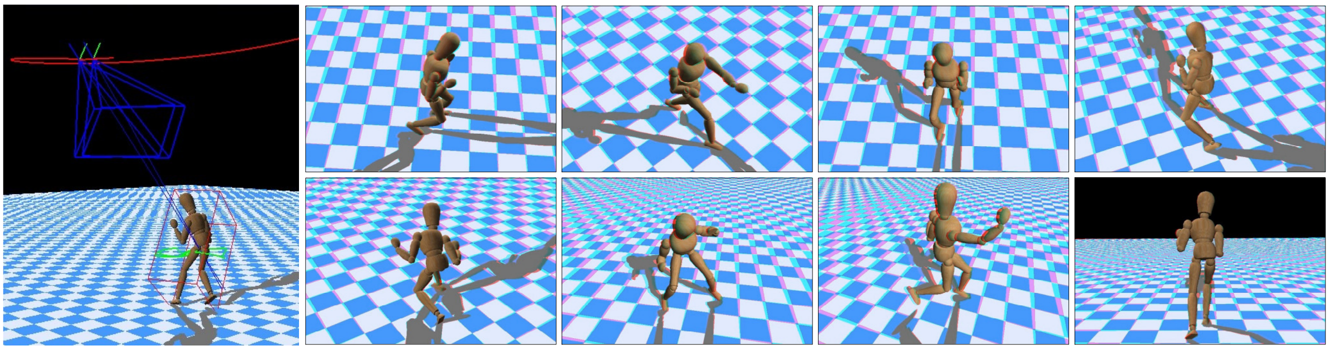

Fig. 8. The character is boxing and the camera moves along a top-down spiral path (left figure). The selected frames are shown (rest figures).

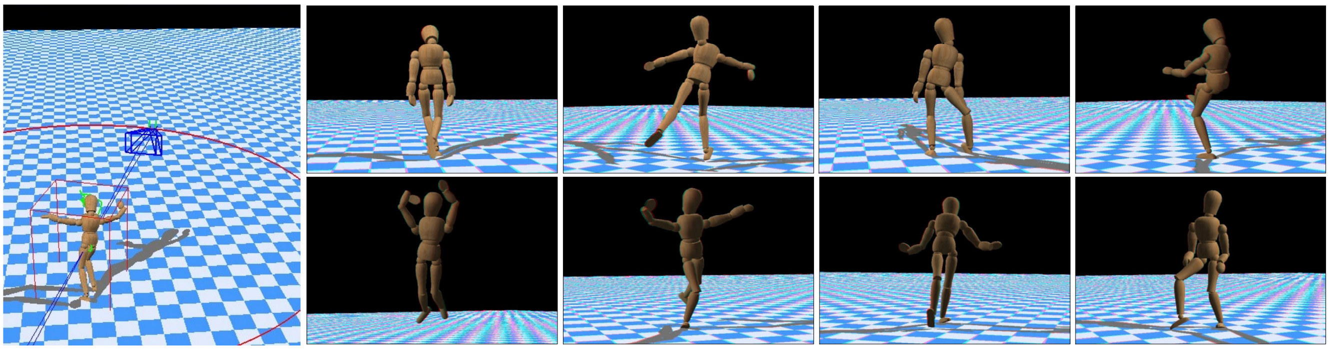

Fig. 9. The character is dancing and the camera moves along a circular path (left figure). The rendering results are illustrated (rest figures).

in sports broadcasting and action films. Recently, the commercial camera with intelligent functions for assisting photographers has become a trend. Generating specific 3D effects in photography may become routine. Besides, our method does not consider the background parallax. This is because our test conditions are dynamic and the interested object is the character motion.

V. Conclusion

We carried out a simulation system for character motion data under a constrained camera path and parallax conditions. The output can be parameter scripts for desired 3D effects. With regard of future issues for study, additional subjective experiments for favor 3D effects should be conducted.

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