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Interaxial Distance and Convergence Control for Efficient Stereoscopic Shooting using Horizontal Moving 3D Camera Rig

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Abstract**—**The proper assessment of interaxial distance and convergence control are important factors in stereoscopic imaging technology to make an efficient 3D image. To control interaxial distance and convergence for efficient 3D shooting, horizontal 3D camera rig is designed using some hardware components like 'LM Guide', 'Goniometer' and 'Rotation Stage'. The horizontal 3D camera rig system can be properly aligned by moving the two cameras horizontally in same or opposite directions, by adjusting the camera angle and finally considering horizontal swing as well as vertical swing. In this paper, the relationship between interaxial distance and convergence angle control are discussed and intensive experiments are performed in order to demonstrate an easy and effective 3D shooting.

Keywords**—**Interaxial, Convergence, Stereoscopic, Horizontal 3D Camera Rig

I. Introduction

CONSIDERING human visual cortex system to see any 3D image with one eye, an object can be considered as 3-dimensional from the subconscious mind but actually it is illusion of an image which appears like 3D when viewed with only one eye. The creation of stereoscopic imaging is originated based on the concept that when a single image with slightly different positions is captured using two cameras at the same time, then on imbricating two images over one another, a 3D image can be developed which can be seen using both eyes together wearing polarized glasses.

Some of the factors which are crucial for the formation of a clear 3D image depend on the static and dynamic information. Static information includes accommodation, interposition, size, texture gradient, linear perspective, shading, and height while dynamic information includes motion parallax and kinetic depth effect.

The static source which normally depends on focus control of eyes includes accommodation and depth information which is used to distinguish relative location of objects in stereoscopic 3D image. The depth perception is applied to visualize the distance between one points and different objects. Secondly it's used to measure the distance between two points among objects. Generally, stereoscopic images provide the realistic sense of 3-dimensions using the human's visual system [1], by injecting two images filmed by 2 cameras. Some of the major factors which are very crucial for making an efficient stereoscopic 3D image include interaxial distance between two cameras and convergence control of different objects in an image.

The position of two eyes in human visual system are fixed but when the interaxial distance between the two cameras is considered, the horizontal distance between them varies in order to capture an image with different positions either moving both cameras towards or opposite of each other. By adjusting the interaxial distance between cameras, the depth can be increased or decreased of an image. To make technically stable stereoscopic images, different types of lenses, screen size and the distance between both cameras and object are considered for the experiment.

The second factor "Convergence" determines the different points where an object appears in relation to the screen. Convergence can be adjusted by toed-in (an inwardly-angled adjustment) of the cameras or by horizontal image translation (H.I.T). Interaxial distance and convergence are crucial to determine better quality of stereoscopic image but practically it is difficult to determine the proper interaxial distance and convergence angle according to the shooting range.

In this paper, a novel decision method for proper interaxial distance and convergence control is presented to make an efficient stereoscopic image using horizontal 3D camera rig. From experiments, information of proper interaxial distance and convergence angle is provided considering different shooting ranges.

II. Related Works

Sometimes, a troublesome problem occurs with Virtual Reality when viewers suffer from motion sickness-like symptoms popularly called as cybersickness [2]. This symptom is mainly occurred when there is difference in the virtual distance comprehended by horizontal disparity and focus, causes eyestrain or headache. To reduce the cause of cybersickness, a mechanism is designed in order to control both vergence and focus control [3].

A binocular stereoscopic camera is developed to control the vergence using disparity information by simple image processing methods [4]. In this proposed method, variance in the distance of the key object is considered as well as disparity information of left and right images are calculated.

Another factor called as "Interocular distance" between two

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cameras is important to control vergence and focus which is helpful for binocular depth perception. For each alignment of the cameras, interocular distance is varied and their effect on the depth is observed. The relationship between interocular distance and the experimental results indicate that the use of stereoscopic projections greatly enhance the depth perception and better 3D visualization information rather than using monoscopic projections [5].

III. Relationship between Interaxial distance and Convergence

Convergence points play an important role to create the effect of depth perception in a stereoscopic image. After determining a single convergence point in an image, three parallax positions are considered which includes positive parallax, zero parallax and negative parallax. Zero parallax is considered as the reference point where both the eyes converge at the same point on an object. On a stereoscopic monitor, the image at zero parallax will form on the monitor surface. Positive parallax occurs when the eye axes converge at the point at the back of the object which is earlier considered as reference placed at zero parallax. This situation would result in a stereoscopic image being formed behind the plane of the monitor. The objects placed in positive parallax regions usually bring cybersickness to the viewers who watch a 3D movie or play any 3D game. Negative parallax can be used to project images between zero parallax and the viewer's eye position, giving the appearance of objects coming out of the monitor. The viewer tries to focus on the screen, but the eyes converge in the negative parallax region which brings the illusion that objects are coming out of the monitor or screen.

These parallax techniques allow the image to be correctly projected in front or behind the monitor plane, within the physical limits of the eye movement. When stereoscopic shooting is performed parallel, the zero parallax point appears to be at infinity, giving illusion that every object placed in negative parallax regions. For convergence control, the proper alignment of convergence angles is required.

When shooting is performed with toed-in convergence, there is a chance of keystone distortion, which is obtained by different perspective views of the same scene. If the cameras have excessive toed-in convergence, there is a risk of background deviation making the 3D image very difficult to view [6].

To reduce keystone distortion, two camera`s convergence angle should be moved equally. So, proper camera convergence angle according to the distance of interaxial distance and convergence point can be obtained. Fig. 1 shows about the concept of converging points and angles using two cameras.

In Fig. 1, D is the distance between convergence point and camera, T is interaxial distance between the two cameras, θ1 is the camera's angle of view, θ2 is the camera's moving angle, and θ3 is the convergence angle.

Table I show about the calculative values of all three angles obtained by considering interaxial and convergence point distance using (1), (2) and (3) respectively.

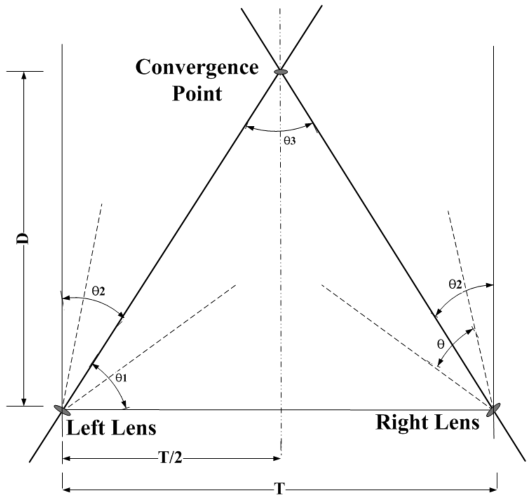


Fig. 1 Relation between interaxial distance and convergence point

$$\theta 1 = \arctan (D/ (T/2)) \quad (1)$$

$$\theta 2 = 90 \text{ degree} - \theta 1 \quad (2)$$

$$\theta 3 = \theta 2 \times 2 \quad (3)$$

In (4), base is interaxial distance, lens is camera's image sensor size and parallax is the difference between left and right camera images.

$$Base = Lens \times \frac{Parallax}{100} \times \left(\frac{Far \times near}{Far - near} \right) \times \left(\frac{1}{Lens} - \frac{Far - Near}{Near \times Far} \right) \quad (4)$$

IV. Design of horizontal camera rig

To obtain an efficient stereoscopic 3D image, two digital cameras which can be placed on a platform called as 'rig' is required. For interaxial and convergence control, there are two kinds of rig system. Firstly, in a 'Horizontal' rig, the cameras are mounted parallel to each other. Secondly, the 'mirror' or 'beam splitter' rig places one camera horizontally, the other vertically. A semi-transparent mirror reflects the image into the vertical camera while allowing the horizontal camera to see through the mirror. The interaxial distance on a rig can be small sufficient for suitable close shooting.

In this paper, horizontal 3D camera rig system is designed that can be used to control the interaxial distance and convergence.

To control the distance between the two cameras, LM (Linear Motion) guide is used. To endure weight of other part, it consists of material of larger strength. To set alignment of two camera images, goniometer and rotation stages are used. Both stages of the same hall size (M4) can be assembled together. In goniometer stage, horizontal swing and vertical swing are adjusted by means of lining two axes.

Both the axes are aligned in the form of dovetail types and their control limits are 15 degrees. In rotation stage, tilting of both cameras are performed by changing different camera angles to get proper alignment of images. 'Goniometer' and 'Rotation Stage' both are equipped with bearings and angle is marked on their circumferences.

TABLE I
RELATION INTERAXIAL DISTANCE AND CONVERGENCE

T (mm)	D (m)	θ 1(degree)	θ 2(degree)	θ 3(degree)
70	4	89.4	0.6	1.2
70	5	89.5	0.5	1
70	6	89.6	0.4	0.8
70	7	89.7	0.3	0.6
70	8	89.74	0.26	0.52
70	9	89.77	0.23	0.46
70	10	89.8	0.2	0.4
100	4	89.2	0.8	1.6
100	5	89.4	0.6	1.2
100	6	89.5	0.5	1
100	7	89.6	0.4	0.8
100	8	89.64	0.36	0.72
100	9	89.68	0.32	0.64
100	10	89.7	0.3	0.6
150	4	88.9	1.1	2.2
150	5	89.1	0.9	1.8
150	6	89.2	0.8	1.6
150	7	89.3	0.7	1.4
150	8	89.4	0.6	1.2
150	9	89.5	0.5	1
150	10	89.57	0.43	0.86
200	4	88.5	1.5	3
200	5	88.8	1.2	2.4
200	6	89	1	2
200	7	89.1	0.9	1.8
200	8	89.2	0.8	1.6
200	9	89.3	0.7	1.4
200	10	89.4	0.6	1.2

TABLE II
CAMERA RIG SPECIFICATION

Goniometer Stage	
Stage Surface (mm)	60□60
Rotation Center (mm)	60
Travel Range (degree)	15
Travel Guide	Dovetail Type
Resolution	0.1/vernier
Load Capacity (kg/f)	6
Weight (kg)	0.175
Rotation Stage	
Stage Surface (mm)	60□60
Travel Range (degree)	360
Travel Guide	Crossed roller Type
Reading	0.1/vernier
Load Capacity (kg/f)	4.5
Weight (kg)	0.21
LM Guide	
Block Dimensions (mm)	57x 34x 24
Rail Dimensions (mm)	120x 15x 12.5
Basic Dynamic Load Rating (kN)	9.51
Basic Static Load Rating (kN)	19.3
Static Rated Moment (kgf.m)	10
Block Weight (kg)	0.2
Rail Weight (kg/m)	1.2

Table II shows the specification of LM Guide, Rotation, and Goniometer.

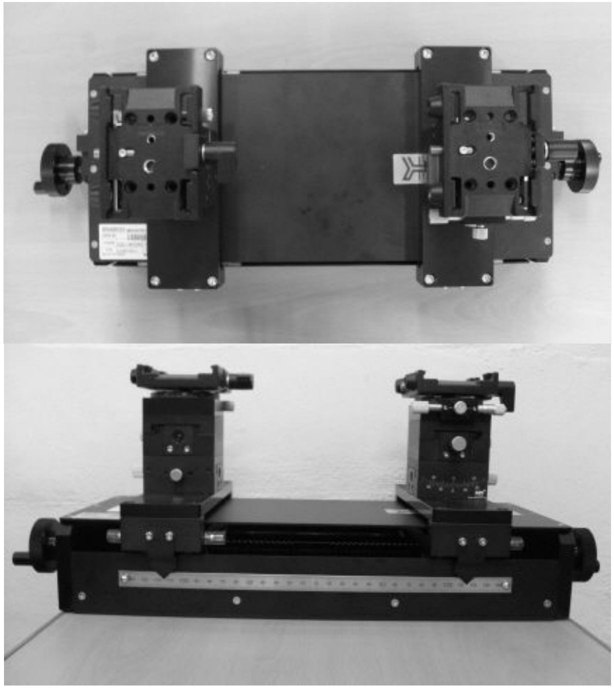


Fig. 2 Horizontal 3D Camera Rig

Fig 2 shows the horizontal 3D camera rig system which has been designed using 'LM Guide' to adjust camera distance, 'Goniometer' to perform alignment, 'Rotation' to adjust convergence angle and 'Plate' to assemble camera rig and camera.

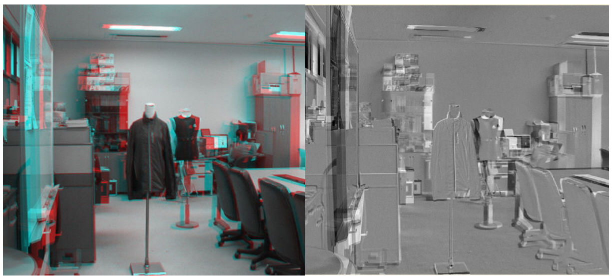
V. EXPERIMENTS AND RESULTS

Experiments are performed considering the different object distances to control interaxial distance and convergence using designed horizontal 3D camera rig system. To start the experiment, 35 mm image sensor and 50 mm normal lens are used. Native Pixel Parallax (NPP) information is used to confirm stability of the results. The NPP equation is (interaxial distance/ screen width x screen resolution). If screen width is 1 m, resolution is 1920 then NPP is 120 pixels. For the experiment, 500 mm screen and 1280 resolutions are used then NPP of binocular distance (65 mm) is 160 pixels.

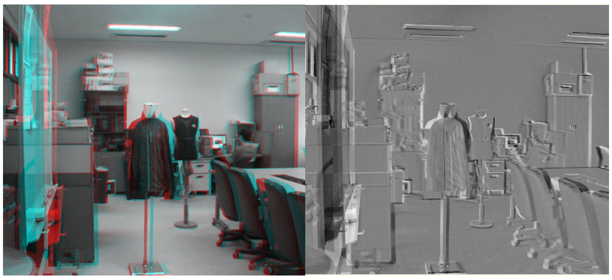
Fig. 3 shows the experiment condition of narrow shooting where the range is of 3m~12m. The distance between the two cameras and the first mannequins is 4m and to the second mannequins is 7m. Proper interaxial distance is 80mm ~120mm according to (4).

Fig. 4 shows experimental results of the images using anaglyph method (left image) and disparity detection (right image). In Fig. 4 (a) and Fig. 4 (b), the interaxial distance in both figures is 100 mm. According to table II, in Fig. 4 (a), the camera angle is about 0.8 degree and convergence angle at first mannequins consists of 1.6 degrees whereas in Fig. 4 (b), the camera angle is 0.4 degree and convergence angle for second mannequins is 0.8 degrees respectively. Fig. 4 (a) has maximum pixel parallax as 130; average pixel parallax as 90 while Fig. 4 (b) has maximum pixel parallax as 100 and average pixel parallax as 70.

Fig. 3 Experiment condition of narrow shooting range



(a)



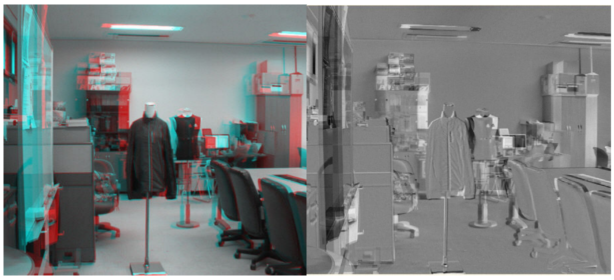
(b)

Fig. 4 Experiment image (a) image using interaxial distance 100 mm and convergence point distance 4 m (b) image using interaxial distance 100 mm and convergence point distance 7 m

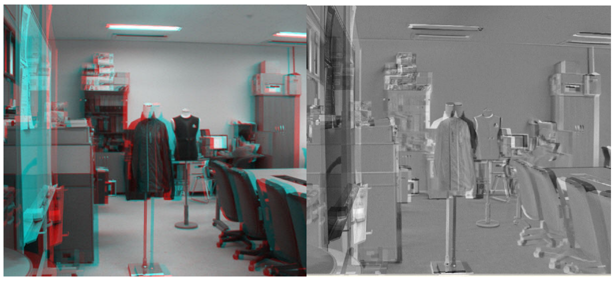
However, both experiments don't exceed 160 pixels according to the standard NPP condition. So, shooting image in both the figures can be seen in stable range of vision without any visual fatigue.

Similarly, Figure 5 shows the experimental results using interaxial distance 200 mm. According to Table III, in Fig. 5 (a), the camera angle is about 1.5 degrees and the convergence angle at first mannequins consists of 3 degrees while in Fig. 5 (b), the camera angle is about 0.9 degree and convergence angle at second mannequins consists of 1.8 degrees respectively.

Fig. 5 (a) has maximum pixel parallax as 180; average pixel parallax as 120 while Fig. 5 (b) has maximum pixel parallax as 140 and average pixel parallax as 100. In case of Fig. 5 (a), the interaxial distance is excessively stretched in narrow shooting range and convergence point is too near. So, it might makes tiredness of vision because parallax difference between left camera image and right camera image is over 160 pixels.



(a)



(b)

Fig. 5 Experiment image (a) image using interaxial distance 200 mm and convergence point distance 4 m (b) image using interaxial distance 200 mm and convergence point distance 7 m

In Fig. 5 (b), the parallax pixel can be reduced by adjusting convergence point to middle of shooting (second mannequins) range. Fig. 5 (b) is better than Fig. 5 (a) because in Fig. 5 (b), the maximum pixel parallax doesn't exceed 160 pixels. However, if the interaxial distance is more then by adjusting the proper converging points, a clear 3D image can be obtained which is shown in Fig. 5 (b).Fig. 6 shows experimental condition of wide shooting range of 10 m~25 m where the camera distance with the first mannequins is 20m and with the second mannequins is 30 m. Proper interaxial distance is over 250 mm.

In Fig. 6 (a), the interaxial distance is 100 mm and the convergence point object is first mannequins. According to Table II, camera angle is about 0.25 degree and convergence angle consist of 0.5 degree. Considering Fig. 6 (b), the interaxial distance is 100 mm and the convergence point object is 'man'. The camera angle is about 0.2 degree while the convergence angle consists of 0.4 degree. Fig. 6 (a) has maximum pixel parallax as 90, average pixel parallax as 60 while Fig. 6 (b) has maximum pixel parallax as 70, average pixel parallax as 40.

Here, interaxial distance is same as in Fig. 4, but since the shooting range of different objects get increased, therefore, both Fig. 6 (a) and Fig. 6 (b) can't able to produce 3D image of good clarity as comparison to Fig.4.

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In Fig. 7 (a), the interaxial distance increases to 200mm and the convergence point object is first mannequins. According to Table II, camera angle is about 0.3 degree and convergence angle consist of 0.6 degree. In Fig. 7 (b), the interaxial distance is same and convergence point object is ‘man’. The camera moving angle is about 0.23 degree and convergence angle consist of 0.46 degree. Fig. 7 (a) has maximum pixel parallax as 120, average pixel parallax as 90 while Fig. 7 (b) has maximum pixel parallax as 110, average pixel parallax as 70.

Fig. 6 Experiment condition of wide shooting range

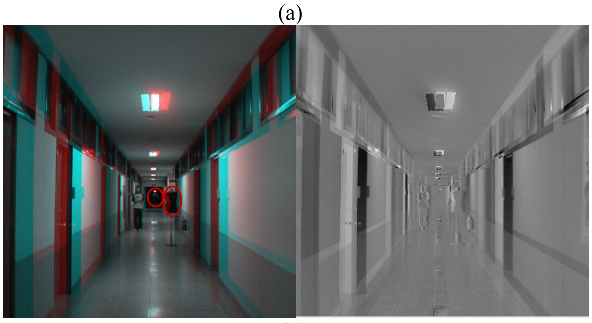
(a)

(b)

Fig. 6 Experiment image (a) image using interaxial distance100 mm Convergence point distance 15 m (b) image using interaxial distance100mm Convergence point distance 20 m

By increasing interaxial distance, stereoscopic effect of low quality is obtained because of big difference between two images parallax. Here, the shooting range between the camera and objects is more. Therefore, to obtain a clear 3D image, depth visualization between the ‘man’ and the convergence point at first mannequins is considered. Fig. 7 (a) has better depth visualization than in Fig. 7 (b) because depth between ‘man’ and convergence point at first mannequins in Fig. 7 (a) is more than the depth between second mannequins and convergence point taken at ‘man’ as in Fig. 7 (b). Hence, 7 (a) has better 3D effect.

(a)



(b)

Fig. 7 Experiment image (a) image using interaxial distance200 mm Convergence point distance 15 m (b) image using interaxial distance200 mm Convergence point distance 20 m

VI. CONCLUSION

The alignment of cameras on horizontal rig system is key factor for an effective shooting of a 3D image. Hence, a horizontally moving 3D camera rig system is developed to get 3D video. The relationship between interaxial distances and convergence control and their effects in the process of shooting stereoscopic images are discussed and several experiments are performed. Various experiments are performed by changing different interaxial distances between the cameras in order to enhance the better quality of 3D visualization. By proper adjustment of convergence and focus control according to guide line proposed by the study in this paper, the cybersickness in viewers can be reduced very effectively

TABLE III
EXPERIMENT RESULT

Interaxial (mm)	Convergence point(m)	Max Parallax(pixel)	Average Parallax(pixel)
100	4	130	90
100	7	100	70
200	4	180	120
200	7	140	100
Interaxial (mm)	Convergence point(m)	Max Parallax(pixel)	Average Parallax(pixel)
100	15	90	50
100	20	70	40
200	15	120	90
200	20	110	70

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