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Development of a New Single Beam Omnidirectional Projector and its Application in Tele-robotic System

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Abstract: The purpose of the research is to improve the development of the omnidirectional images by using the single beam projector, which is combined with the low cost and reasonable hardware and software. We project the 360-degree images to the cylindrical screen in space through the omnidirectional projecting system and make a Tele-present immediately. The operators will be able to see the 360-degree omnidirectional images, which are just like in the actual situation. In this research, we develop the low cost omnidirectional projecting system by combining the self-made conical mirror with the general projector. It makes the operator's view be wider and replaces the conventional projector to improve the fault of that the view angel is not enough and the images are discontinuous. Moreover, the omnidirectional projecting system not only saves space but also improves the fault of traditional monitor system, which causes to waste spaces due to its need of using more projectors and closed-circuit televisions when monitoring the same space. Otherwise, it would not make the operator feel dizzy by using omnidirectional projecting system to replace the Eye-Trek. The omnidirectional projecting system is combined with the haptic interactive motion simulator to form the reality system of the Tele-present system, making the operators feel immersive.

Key words: Omnidirectional projector, omnidirectional image, panoramic image, tele-robotic, catadioptric sensor

INTRODUCTION

Today, most of the research about the omnidirectional vision system is discussing the part of photography, which is about the omnidirectional camera. According to literature, Baker and Nayar (1998) used a general camera to combine with the parabolic mirror which has the quality of a single viewpoint, gathering the light in all direction through the extension line of viewpoint of parabolic mirror and then reflect it to the image plane of the lens of camera to obtain the omnidirectional image.

In the research about the image calibration, transforming the omnidirectional image into the cylindrical panoramic image (Liu *et al*., 2003) separated the polar coordinate from 0 to 360-degree into X-Y coordinate and transformed the radial line of omnidirectional image to the perpendicular line. After the compute by the equation, the author got the non-distortion image. In addition, Hua *et al*. (2007) mounted the four conventional cameras on top of hexahedron mirror and captured the images, then made the image calibration. Otherwise, Fan and Qi-dan (2009) proposed the Project on Convex Sets (POCS) method, it can be applied to find a vector which belongs to the intersection by the recursion, then get high resolution transformed image which is transformed from panoramic image. Moreover, Lui and Jarvis (2010) arranged the two omnidirectional cameras side by side in the same vertical line, in addition to estimate the coordinate of any point in 3D space, but also used automatic baseline selection process to do camera calibration.

Hence, the research about rotation angles and motion of the omnidirectional camera, Bravo-Valenzuela and Torres-Torriti (2009) made the two omnidirectional cameras are horizontal arrangement side by side, or vertical arrangement of two, then measured the coordinate of objects in the 3D space instead of the conventional stereo vision. Magnier *et al*. (2010) proposed a new method for omnidirectional camera pose estimation. It is also base on single viewpoint property to estimate the orientation of the catadioptric device by exploring a sampled space of different possible orientation and associating a histogram to each orientation. Besides, Lu and Zheng (2010) applied the Features from Accelerated Segment Test Local Binary Pattern (FAST+LBP) and Features from Accelerated Segment

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Test (FAST+CSLBP) algorithm on the panoramic images to detect the corner features of panoramic images, then estimated the translation and the rotation of these features.

As for the application of the omnidirectional camera, Drocourt *et al.* (2006) set up two omnidirectional cameras on the robot to estimate its position of the unknown environment and Caron and Mouaddib (2009) used four parabolic mirrors and orthographic camera to develop the omnidirectional stereovision. It could be used on vertical line matching and mobile robot indoor localization and Liu and Mehrandezh (2007) placed the omnidirectional camera on an Automated Guided Vehicle (AGV) and estimated the rotational angle (pitch, roll, yaw) of AGV when it was walking on the street via the omnidirectional image.

In the application of Unmanned Aerial Vehicle (UAV), Demonceaux *et al.* (2007) mounted the omnidirectional camera on the UAV, then measured the pitch and roll angle by capturing the horizontal and vertical lines and Mondragon *et al.* (2010) mounted the omnidirectional camera under the head of helicopter to estimate the rotational angle (pitch, roll, yaw) and its trajectory by capturing the horizontal line when it was flighting.

Other applications such as: Hadj-Abdelkader *et al.* (2006) found the trajectories of visual features imaged through the omnidirectional cameras corresponding to a minimal camera trajectory and Hadj-Abdelkader *et al.* (2008) used the omnidirectional image to estimate the coordinate of objects, then transmitted the coordinates to the manipulator via server, so the manipulator could capture the objects and Tahri *et al.* (2009) placed the omnidirectional camera on the central Gough-Stewart platform and got the omnidirectional image, it could be noticed that the variation of the orientation by using leg edges in the control is robust and less noisy than using leg orientations, as well as Ikeuchi *et al.* (2004) placed the omnidirectional camera on the vehicle, allowing it to capture the images when the vehicle was proceeding along the street and then analyzed the images. After that, they made the 3D model of buildings overlap in the original images of the city. And the environment of virtual city is resulted, Utsumi and Iwai (2009) also applied the Haar wavelet on the omnidirectional images to detect the facial features, then finished a face tracking and face recognition based on a Bayesian framework by using multiple omnidirectional camera.

In the low cost image system application of virtual reality, Her *et al.* (2008) used two low cost webcam to capture the computer game screen and presented it on another computer, then the operator could operate the computer game immediately.

According to the above literatures, we find the most of the researches of the omnidirectional vision system focus on the camera. However, there is a little research about the projection. For example, Astre *et al.* (2008) got the omnidirectional image by rotating the camera, then projected the image on the cube screen, but the screen is not the 360-degree cylindrical screen, so the presentation of the scene is limited. In addition, the use of reflect mirror, the most of researchers usually use catadioptric sensor or complex shape mirrors which were made by themselves, furthermore the manufacturing process is complicated and high-cost (Hua *et al.*, 2007). Finally, in the application of virtual reality, most of the virtual scene is a 2D plane or the operator wears the Eye-Trek glasses. It would be resulted that the scene is not the stereovision or the operator feels dizzy.

In this research, we refer the theory of omnidirectional camera and its hardware architecture to develop the low cost and reasonable omnidirectional projecting system. It makes the operators to see the scenes that are similar to the real environment and enjoy the immersive ambiance.

DESIGN OF THE OMNIDIRECTIONAL PROJECTING SYSTEM

In this research, we capture a remote image, which is omnidirectional image by the omnidirectional camera and then it would be transmitted to the server operator by wireless. Furthermore, according to the reversible theorem of optical path, we project the omnidirectional image to the 360-degree cylindrical screen by the omnidirectional projecting system. After that, the operator can see the 360-degree scene. The overall design concept is shown as Fig. 1.

The hardware design of the omnidirectional camera: In the process of design, in order to reduce costs, we use the self-made conical mirror and the general webcam to substitute for the omnidirectional webcam. The size of it is small, as shown in Fig. 2. It can be set up on the Automated Guided Vehicle (AGV); and while the AGV is running, it captures the scene to be the omnidirectional image.

The hardware design of the omnidirectional projector: In this research, we also combine the self-made conical mirror with the general projector and project the omnidirectional image, which is captured by remote to the 360-degree cylindrical screen, then makes it become a

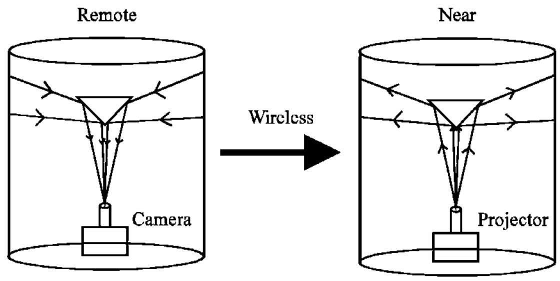

Fig. 1: Present the remote scene by the omnidirectional projecting system

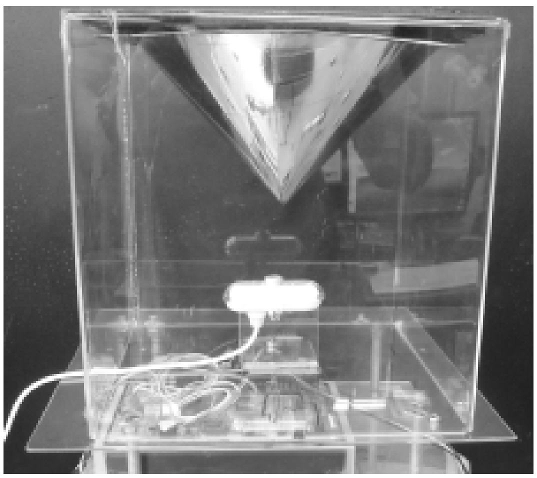

Fig. 2: Omnidirectional camera

omnidirectional projecting system. The radius of the self-made conical mirror is R = 21cm; the angle is $\beta = 45°$; the angle of view of the projector is $62°(\alpha_P = 31°)$; and the distance between the center of the projector and cylindrical screen is d = 150 cm, each parameters as shown in Fig. 3.

Theoretical analysis of the omnidirectional projecting system: As the geometric analysis of the omnidirectional projecting system in Fig. 3 shows the distance between the lens and the screen is d, which we set d is constant; then we properly adjust the distance between the lens and the conical mirror to α and the slope angle of the conical mirror to β. Finally, we obtain the size of the ribbon image, which is projecting on the cylindrical screen, h_1. The process follows the formula derived.

First, from the ΔOAE and the law of cosines, we obtain:

$$b = \frac{2a\cos\alpha + \sqrt{(2a\cos\alpha)^2 - 4(a^2 - c^2)}}{2} \qquad (1)$$

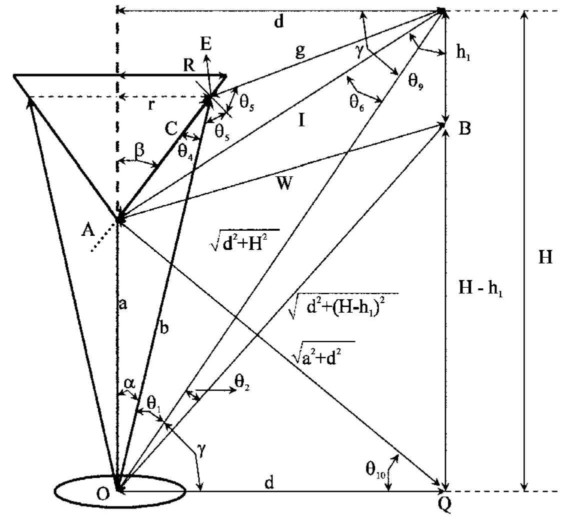

Fig. 3: Geometric analysis of the omnidirectional projecting system

which is $c = r/\sin\beta$.

Second, from the ΔOPE, we obtain:

$$g = \sqrt{b^2 + d^2 + H^2 - 2b\cos\theta_1\sqrt{d^2 + H^2}} \qquad (2)$$

which is:

$$\theta_1 = \frac{\pi}{2} - \alpha - \tan^{-1}\frac{H}{d} \qquad (3)$$

Third, from the ΔOPA, we obtain:

$$I = \sqrt{a^2 + d^2 + H^2 - 2a\sqrt{d^2 + H^2}\cos(\alpha + \theta_1)} \qquad (4)$$

which is:

$$\theta_5 = \frac{\pi}{2} - \theta_4 = \frac{\pi}{2} - \cos^{-1}\frac{b^2 + c^2 - a^2}{2bc} \qquad (5)$$

Fourth, from the ΔPAB, we obtain:

$$\cos\theta_9 = \cos\left(\frac{\pi}{2} - \gamma + \theta_6\right) = \cos\frac{I^2 + h_1^2 - w^2}{2Ih_1} \qquad (6)$$

which is:

$$\theta_9 = \theta_6 + \left(\frac{\pi}{2} - \gamma\right) = \cos^{-1}\frac{I^2 + d^2 + H^2 - a^2}{2I\sqrt{d^2 + H^2}} + \frac{\pi}{2} - \gamma \qquad (7)$$

Fifth, from the ΔOAB, we obtain:

$$\cos(\alpha+\theta_1+\theta_2)=\frac{a^2+\left(\sqrt{d^2+(H-h_1)^2}\right)^2-w^2}{2a\sqrt{d^2+(H-h_1)^2}} \quad (8)$$

Sixth, from the ΔOPB, we obtain:

$$\cos\theta_2=\frac{\left(\sqrt{d^2+H^2}\right)^2+\left(\sqrt{d^2+(H-h_1)^2}\right)^2-h_1^2}{2\sqrt{d^2+H^2}\sqrt{d^2+(H-h_1)^2}}=\frac{d^2+H^2-h_1H}{\sqrt{(d^2+H^2)\left(d^2+(H-h_1)^2\right)}} \quad (9)$$

Seventh, from the ΔQAB, we obtain:

$$\cos\left(\frac{\pi}{2}-\theta_{10}\right)=\frac{\left(\sqrt{a^2+d^2}\right)^2+(H-h_1)^2-w^2}{2(H-h_1)\sqrt{a^2+d^2}} \quad (10)$$

which is:

$$\theta_{10}=\tan^{-1}\frac{a}{d} \quad (11)$$

Finally, we solve the unknown value of h_1, w and θ_2 by the Eq. 6, 8, 9 and 10, which h_1 is the width of ribbon image projected on the cylindrical screen that the research is studying for.

EXPERIMENT AND RESULT

According to the reversible theorem of optical path and the theoretical analysis of the omnidirectional projecting system, we design the experiments as follow. In the experiment, the initial conditions for all experiments are: the distance between the camera and the screen, d_C, is 150 cm; the distance between the projector and the screen, d_P, is 150 cm; the view angle of the camera is 32-degree ($\alpha_C = 16°$) and the view angle of the projector is 62-degree ($\alpha_P = 31°$). The experiments are as follow:

Experiment 1. Combining the Pyramid Mirror with the Camera or Projector: In the experiment, we use the self-made pyramid mirror in order to reduce costs, understand the relationship between the reflect mirror, the projector and camera. First, we capture the image by using camera with different angles β of the pyramid mirror, then project the image to the front, back, left and right screen by using projector with different angles of the pyramid mirror, as shown in Fig. 4.

According to this experiment, the image, which is projecting on the screen, is the most clear when the angle of the pyramid mirror is 45-degree. However, it resulted

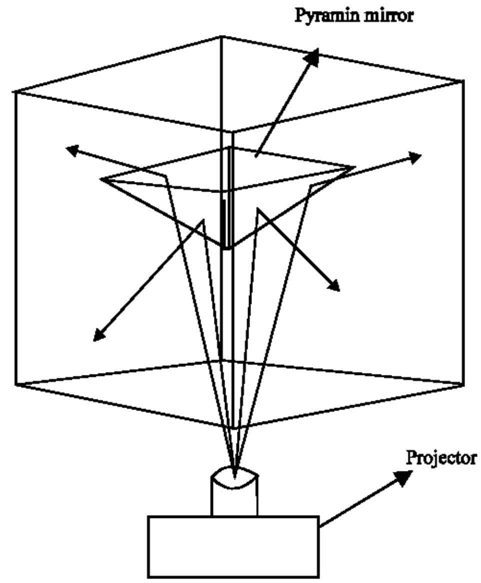

Fig. 4: Using the projector with pyramid mirror to project the image to the front, back, left and right screen

the view angle in insufficiency due to that the reflect mirror is the four-faced pyramid mirror; hence, it can only project the image to the four directions: front, back, left and right, but it cannot be to the right front, left front, right rear and left rear images. Due to the above reason, in order to improve the problem of the insufficiency of view angle, we increase the number of the mirror step by step to make the reflect mirror become a conical mirror.

Experiment 2. Discuss the Distance of the Projector and the Mirror: The purpose of this experiment is to obtain the distance between the projector and the conical mirror as well as the width of ribbon image projected on the cylindrical screen, which is h'_1, when the size of the image projected on the screen is most similar to the original one. Moreover, since the conical mirror is similar to be constructed by many mirrors whose widths are extremely small; in the experiment, we use a single mirror to substitute for the conical mirror in order to properly adjust the angle of conical mirror. By that, we can easily obtain the distance between the camera and the conical mirror as well as the distance between the projector and the conical mirror. According to the Fig. 3 of geometric analysis of the omnidirectional projecting system, we set the initial condition of the experiment to be that the angle of mirror is β = 45° and the experiment steps are as follow:

- **Step 1:** The experiment is based on a 15×15 cm^2color square as its measure. Firstly we assume that the distance between the projector and the mirror is α_P; then we adjust the distance, α_C, which is the distance between the camera and the mirror. In the meanwhile, we capture the image of the color square via the reflect mirror. After that, we project the image of the color square to the screen via the reflect mirror to make the image size similar to 15 cm and record α_C. The experimental data is shown on Table 1. According to the Table 1, we can only adjust the size of color square image into 14.65 cm due to the space is limited when the α_C is 5.9 cm, so we obtain a range of value α_P which is between 50 to 60 cm, that it means the range of value α_C is between 24.3 to 33.8 cm. Finally, we obtain the most suitable distance between the camera and the mirror to be as α_C = 28 cm

- **Step 2:** According to Step 1, we set the most suitable distance between the camera and mirror to be as α_C = 28 cm; then we adjust the distance between the projector and the mirror, which is α_P. After that, we project the image of the color square that is captured on the screen via the projector and the reflect mirror, measuring the size of image and compare the size with actual color square. As shown in Table 2, we obtain the experimental data that shows the size of color square image is most similar to the actual color square when the α_P = 55 cm
- **Step 3:** As Fig. 5 shows, when we measure the size of color square image, we also measure the experimental value of width of ribbon image, which is h'_1 and the height position of ribbon image, H, on the screen at the same time. After that, we take the H, α, d and $\alpha = \alpha_P$ to be the substitution to solve the Eq. 6, 8, 9 and 10. By that, we obtain the theoretical value h_1, then calculate the error of experimental value (h'_1) and theoretical value (h_1). The experimental data is shown in Table 3

Experiment 3. Discuss the Relationship between the Angle of Mirror and the Image: The purpose of this experiment is to obtain the proper angle of conical mirror to make the image on the cylindrical screen similar to the original one. As same as the Experiment 2, we use a single mirror to substitute for a conical mirror and manufacture a device that can measure the angle of mirror, as shown in Fig. 6.

According to the Experiment 2, the size of color square image is most similar to the actual color square when the initial condition of the distance between the camera and the mirror is set to be as α_C = 28 cm and the distance between the projector and the mirror be

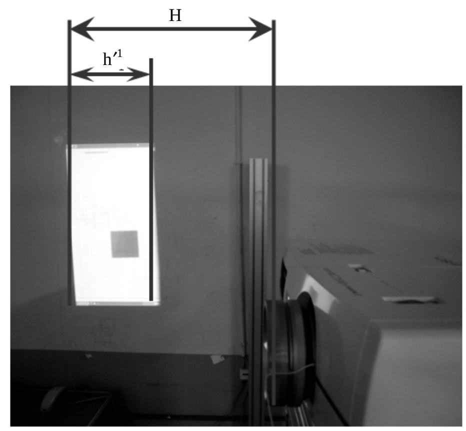

Fig. 5: Measuring the height position of ribbon image H on the screen

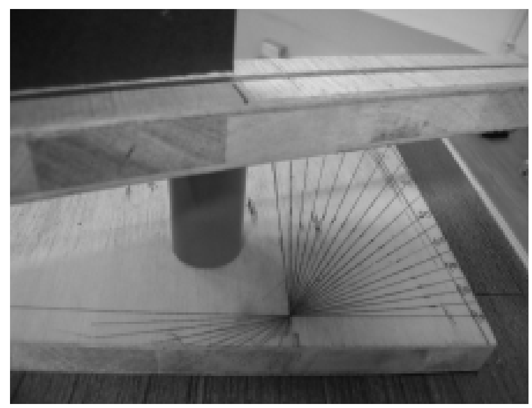

Fig. 6: Measuring the angle of mirror

α_P = 55 cm. Then, we adjust the angle of mirror, which is β_P. At last, we discuss the response of β_P to the size of color square image. The steps of experiment are as follow:

- **Step 1:** The experiment is based on a 15×15 cm^2 color square as its measure. We set the angle of mirror to be as β_C = 45° at the camera, then we use camera to capture the image of the color square via reflect mirror
- **Step 2:** As Fig. 6 shows, we adjust the angle of projection mirror, which is β_P; then we use projector to project the image which is captured by Step 1 to the screen via reflect mirror and measure the size of color square image at the same time. Moreover, comparing the size of color square image with the actual color square, we compute the error. The experimental data is shown on Table 4. Finally, we can obtain the most proper angle of mirror at projector: β_P = 45°

Fig. 7: Camera captures five images of color square via the conical mirror

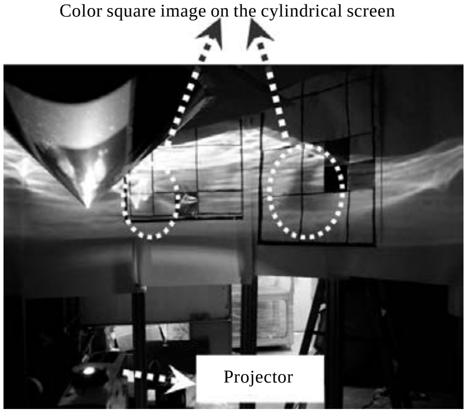

Fig. 8: Projecting the image captured on the cylindrical screen via the conical mirror and compare with the actual color square.

Experiment 4. Test of the Omnidirectional Projecting System: By synthesizing the data acquired from the Experiment 1, 2 and 3, we set the most proper parameters of this experiment and use these parameters to design the omnidirectional projecting system. The parameters of the system are as follow: the distance between the camera and the conical mirror is α_C = 28 cm; the distance between the projector and the conical mirror is α_C = 55 cm; and the angle of conical mirror is $\beta_C = \beta_P = 45°$.

- **Step 1:** As Fig. 7 shows, we put five 15×15 cm^2 color squares on the cylindrical screen. Then we use the camera to capture the image of color squares via the conical mirror
- **Step 2:** As Fig. 8 shows, we use the projector to project the image captured to the cylindrical screen via the conical mirror; and compare the size with the original color square

Table 1: Relationship of the distance between the α_P and α_C

Distance between the projector and the mirror α_P	Distance between the camera and the mirror α_C
(cm)	
75	47.7
70	43.8
60	33.8
50	24.3
40	16.8
30	11.1
20	5.9

The size of color square image is 14.65 cm

Table 2: Setting up the α_C = 28 cm, then adjust the α_P and measure the size of color square image on the screen

Distance between the projector and the mirror α_P	Size of color square image on the screen	Error with the actual color square
	(cm)	
20	13.0	13.33
30	13.2	12.00
40	14.1	6.00
50	14.6	2.67
55	15.1	0.67
60	15.3	2.00
70	16.1	7.33
80	16.9	12.67
90	17.6	17.33

DISCUSSION

Discuss according to the experiments: According to the experiment and theoretical analysis of the omnidirectional projecting system, we find the relationship between every parameter.

Discuss according to the experiment 1: According to Experiment 1, although the image on the screen is very clear after projecting it through the pyramid mirror, the range of the presented image is relatively limited due to the view angle of pyramid mirror is extremely small; especially it cannot present the image to the four 45-degree directions of right front, left front, right rear and left rear.

However, if we increase the number of mirrors and make it to the octahedral cone mirror, we can see the image in four directions: right front, left front, right rear and left rear. If we continue to increase the number of mirrors and make the reflecting mirror reach to the conical mirror, we can obtain the 360-degree omnidirectional image.

Discuss according to the experiment 2: According to the Table 1, as we control the distance between the projector and the mirror α_P and make the color square images in the same size. We realize that when the distance between the projector and the mirror α_P is longer, the distance between the camera and the mirror α_C must be increased. Therefore, we choose a suitable distance to be the best as α_C= 28 cm. Moreover, according to the Table 2, by controlling the

Table 3: Adjusting the α_P, then obtain the error of experimental (h'_1) and theoretical (h_1) values of the size of ribbon image

Distance between the projector and the mirror α_P (cm)	Height position of the ribbon image H (cm)	Size of ribbon image (cm) Experimental h'_1	Theoretical h_1	Error of h'_1 and h_1 (%)
20	55.9	37.3	35.9	3.90
30	82.7	40.5	52.7	23.15
40	95.1	42.9	55.1	22.14
50	109.2	45.5	59.2	23.14
60	122.1	47.0	62.1	24.32
70	142.2	49.5	72.2	31.44

distance between the projector and the mirror α_P, we realize that when the distance is longer and the size of color square image is bigger, the size of ribbon image is more width. We choose one of the distances, which is α_P = 55 cm to make the size of color square image the most similar to the actual color square.

According to the Table 3, when the distance between the projector and the mirror α_P is longer, the size of ribbon image h'_1 on the screen is more width and the error with the theoretical value is bigger. The reason is that the view angle of the projector (α_P) and the camera (α)$_C$ are different. Therefore, when the camera captures images or the projector projects images, the paths of light are different, which makes it not suitable for the reversible theorem of optical; and that is the reason why we obtain the bigger error.

Discuss according to the experiment 3: In the Experiment 3, according to the Table 4, when the angle β_P is between 40 to 60-degree, the error of the size of color square images and the actual color squares is within 5%. However, when the angle β_P is bigger than 60-degree, the error will be bigger than 5%. The reason is that when the angle of mirror is bigger, the length of the color square images will be stretched out even longer. It results in more distortion so that the error is bigger.

Discuss according to the experiment 4: By integrating the statistic from Experiment 1 to 3 and take data into the design of omnidirectional projecting system (Experiment 4), which the angle of conical mirror is β = 45°; the distance between the camera and the conical mirror is α_C = 28 cm; the distance between the projector and the conical mirror is α_C = 55 cm; and the distance between the cylindrical screen and the projector/camera is d = 150 cm.We realize that although the resolution of images projected on the cylindrical screen is lower, the sizes of color square images in Fig. 8 are similar to the actual color square.

Disadvantage and advantage: According to the all of above experiments, we list the disadvantages and advantages of this research as follow:

Table 4: Discussing the relationship between the angles of projection mirror and the actual color square

Angles of Projection mirror β_P (degree)	Size of color square image (cm)	Error with actual color square (%)
40	15.3	2.00
45	14.8	1.33
50	14.7	2.00
55	14.5	3.33
60	14.3	4.67
65	13.7	8.67
70	13.4	10.67
75	13.2	12.00
80	12.4	17.33

- **Disadvantages:** The results of experiment is close to the original expected ones, it shows the 360-degree omnidirectional image, but the image on the cylindrical screen has some distortion, the reason is that the parameters of the projector and camera is not the same, so the paths of light are different when the camera captures the image and the projector projects the image on the cylindrical screen, it is not suitable for using the reversible theorem of optical path. Otherwise, our self-made conical mirror is made of window film, its refraction index is not good, so the resolution of panoramic image on the cylindrical screen is lower.
- **Advantages:** First, compare with the literature, Astre *et al*. (2008) projected the image in the cubic screen; it shows a cubic image which is not the circular image, so the operator's simulated feeling is not close to reality when they see the scene.

Second, compare with the literature, Karkoub *et al*. (2010) wore the Eye-Trek glasses to present the virtual scene, the operator is easy to feel dizzy because the scene of Eye-Trek is too close to the operator's eyes.

In contrast, our research shows an omnidirectional circular image and makes the simulated feeling well, the operator can see the 360-degree scene easily and not feel dizzy.

Finally, compare with the literature, Her *et al*. (2008) used two cameras to capture the image and applied on the stereovision.

In contrast, our research only uses one camera to capture the 360-degree omnidirectional image and only used one projector to show the 360-degree scenes which is similar to stereovision (Fig. 8), so we achieve the purpose of lower cost.

CONCLUSION

In conclusion, we have successfully used the self-made conical mirror with a single beam projector to develop the low cost omnidirectional projecting system. It presents the remote environment immediately. At the same time, the system improves the problem of discontinuous images which occurs when the images are projected by several projectors. Also, it increases the view angle of operators and replaces the Eye-trek for not making the operators feel dizzy.

Finally, when we use the pyramid mirror, although the image is very clear, the range of the view angle of pyramid mirror is not enough that makes the range of presented image is small. Thus, although the resolution of presented image is lower after using a projector with conical mirror instead, we have achieved the purpose of developing the 360-degree omnidirectional image. In the future, we will not only look for the high reflectivity mirror, but also make a program to compensate for image calibration and present the better remote scene by the omnidirectional projecting system.

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REFERENCES

Astre, B., L. Sarry, C. Lohou and E. Zeghers, 2008. Automatic calibration of a single-projector catadioptric display system. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, June 23-28, Anchorage, AK, pp: 1-8.

Baker, S. and S.K. Nayar, 1998. A theory of catadioptric image formation. Proceeding of the 6th International Conference on Computer Vision, Jan. 4-7, Bombay, India, pp: 35-42.

Bravo-Valenzuela, F. and M. Torres-Torriti, 2009. Comparison of panoramic stereoscopic sensors based on hyperboloidal mirrors. Proceedings of the 6th Latin American Robotics Symposium, Oct. 29-30, Valparaiso, pp: 1-8.

Caron, G. and E.M. Mouaddib, 2009. Vertical line matching for omnidirectional stereovision images. Proceedings of the IEEE International Conference on Robotics and Automation, May 12-17, Kobe, pp: 2787-2792.

Demonceaux, C., P. Vasseur and C. Pegard, 2007. UAV attitude computation by omnidirectional vision in urban environment. Proceedings of the IEEE International Conference on Robotics and Automation, April 10-14, Roma, pp: 2017-2022.

Drocourt, C., E. Brassart, B. Marhic and L. Delahochie, 2006. Processing with omnidirectional vision sensors. Proceedings of the 1st IEEE International Conference on E-Learning in Industrial Electronics, Dec. 18-20, Hammamet, pp: 145-150.

Fan, Z. and Z. Qi-dan, 2009. Super-resolution image reconstruction for omni-vision based on POCS. Proceedings of the Chinese Control and Decision Conference, June 17-19, Guilin, pp: 5045-5049.

Hadj-Abdelkader, H., Y. Mezouar and P. Martinet, 2006. Path planning for image based control with omnidirectional cameras. Proceedings of the 45th IEEE Conference on Decision and Control, Dec. 13-15, San Diego, CA, pp: 1764-1769.

Hadj-Abdelkader, H., Y. Mezouar, P. Martinet and F. Chaumette, 2008. Catadioptric visual servoing from 3-D straight lines. IEEE Trans. Robotics, 24: 652-665.

Her, M.G., M. Karkoub and J.M. Chen, 2008. Design and application of a low cost visual tracking system. Aust. J. Electr. Electron. Eng., 4: 191-200.

Hua, H., N. Ahuja and C. Gao, 2007. Design analysis of a high-resolution panoramic camera using conventional imagers and a mirror pyramid. IEEE Trans. Pattern Anal. Mach. Intell., 29: 356-361.

Ikeuchi, K., M. Sakauchi, H. Kawasaki and I. Sato, 2004. Constructing virtual cities by using panoramic images. Int. J. Comput. Vision, 58: 237-247.

Karkoub, M., M.G. Her and J.M. Chen, 2010. Design and control of a haptic interactive motion simulator for virtual entertainment systems. Robotica, 28: 47-56.

Liu, H., W. Pi and H. Zha, 2003. Motion detection for multiple moving targets by using an omnidirectional camera. Rob. Intell. Syst. Signal Process., 1: 422-426.

Liu, W. and M. Mehrandezh, 2007. Visual servoing of a mobile robot in presence of tilt disturbances using a central catadioptric vision system. Proceedings of the Canadian Conference on Electrical and Computer Engineering, April 22-26, Vancouver, BC, pp: 449-452.

Lu, H. and Z. Zheng, 2010. Two novel real-time local visual features for omnidirectional vision. Pattern Recognit., 43: 3938-3949.

Lui, W.L.D. and R. Jarvis, 2010. Eye-full tower: A GPU-based variable multibaseline omnidirectional stereovision system with automatic baseline selection for outdoor mobile robot navigation. Rob. Autom. Syst., 58: 747-761.

Magnier, B., F. Comby, O. Strauss, J. Triboulet and C. Demonceaux, 2010. Highly specific pose estimation with a catadioptric omnidirectional camera. Proceedings of the IEEE International Conference on Imaging Systems and Techniques, July 1-2, Thessaloniki, pp: 229-233.

Mondragon, I.F., P. Campoy, C. Martinez and M. Olivares, 2010. Omnidirectional vision applied to Unmanned Aerial Vehicles (UAVs) attitude and heading estimation. Rob. Autom. Syst., 58: 809-819.

Tahri, O., Y. Mezouar, N. Andreff and P. Martinet, 2009. Omnidirectional visual-servo of a Gough-Stewart platform. IEEE Trans. Rob., 25: 178-183.

Utsumi, Y. and Y. Iwai, 2009. Face tracking and recognition by using omnidirectional sensor network. Proceedings of the 3rd ACM/IEEE International Conference on Distributed Smart Cameras, Aug. 30-3 Sept., Como, pp: 1-8.