An Observation System of Hemisphere Space with Fish eye Image and Head Motion Detector

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Abstract: This paper presents a new observation system which is useful to observe the scene of the remote controlled robot vision. This system is composed of a motionless camera and head motion detector with a motion sensor. The motionless camera has a fish eye lens and is for observing a hemisphere space. The head motion detector has a motion sensor is for defining an arbitrary subspace of the hemisphere space from fish eye lens. Thus processing the angular information from the motion sensor appropriately, the direction of face is estimated. However, since the fisheye image is distorted, it is unclear image. The partial domain of a fish eye image is selected by head motion, and this is converted to perspective image. However, since this conversion enlarges the original image spatially and is based on discrete data, crevice is generated in the converted image. To solve this problem, interpolation based on an intensity of the image is performed for the crevice in the converted image (space problem).
This paper provides the experimental results of the proposed observation system with the head motion detector and perspective image conversion using the proposed conversion and interpolation methods, and the adequacy and improving point of the proposed techniques are discussed.

Keywords: Observation System , Fish eye lens, Image Conversion, Intensity interpolation

1. INTRODUCTION

The requirement of observing the scene of the remote controlled robot vision has been spread in various fields. In this requirement, it is important to obtain the image for an arbitrary subspace of hemisphere space as the scene.

In order to realize this, the control of camera direction in remoteness has to be done by using the tools such as button, control bar and so on, in general. However, there tools are difficult for human operator since human hand sensing and vision are not concurred on occasion. So, we proposed new observation system.

On the other hand, to avoid the control of the camera direction, the researches of the omni-directional vision have been studied [1]-[2]. In the researches, there are multi-camera type and convex mirror with uni-camera type. The former [3]-[4] are high cost and tremendous to treat multi-vision datum. The latter [5]-[6] has a serious problem that process hardly convex mirror in super precision.

Fish eye lens is developed for another image sensing for extensive field [7]-[9]. Since the rate of distortion of fish-eye lens is high compared with a common lens, as for a fish eye lens, fish eye image which maps hemisphere space in the shape of concentric circle is obtained. Thus, fish eye lens has the advantage that omni-directional image can be acquired at the same time. Therefore, in new observation system we focus on fish eye lens, and particularly we consider the omni-directional vision equidistance projection fish eye lens (hereafter denoted as f θ lens).

This paper provides the experimental results of the proposed observation system with the head motion detector and perspective image conversion using the proposed conversion and interpolation methods for a real world, and the adequacy and improving point of the proposed techniques are discussed.

2. NEW OVSERVATION SYSTEM

In this section, a new observation system is explained. The outline of this system is shown in Fig.1. This system has motion sensor [11] shown in Fig.2(a) which detected head motion, HMD shown in Fig.2(b) which projects the obtained image, camera with fish eye lens which obtains the scene and PC for image conversion. Fig.2(c) shown human equipped by motion sensor and HMD. The sensor and the gyro and detect the move angle of X, Y and Z-axis. The detection angle range of the sensor is shown in Table 1.

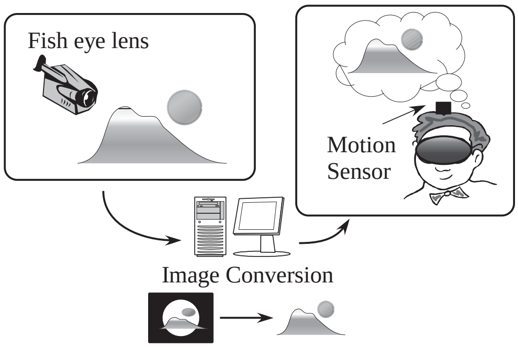
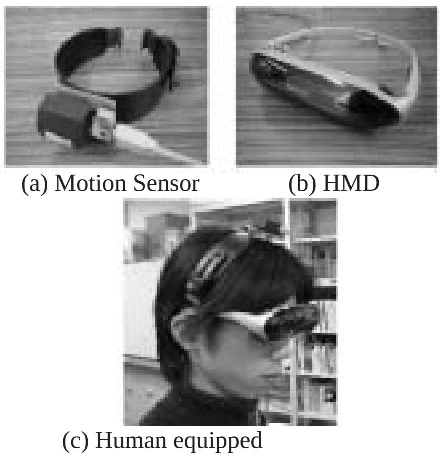


Figure 1: New Observation System



(a) Motion Sensor (b) HMD

(c) Human equipped
by Motion Sensor and HMD

Figure2: Vision Part

Table 1: Detection angle range

Yaw, Z-axis	±180 deg
Pitch, Y-axis	±60 deg
Roll, X-axis	±60 deg

First, the image is obtained with the camera and it ta ken in to PC. Second, a part of obtained arbitrary fish e ye image is chosen with the head motion detector. Howe ver, fish eye image is distorted, and is an unclear image. Thus, fish eye image is converted into the standard ima ge. Finally, obtained standard image is projected on HM D.

3. CONVERSION OF FISH EYE IMAGE

In this section, using projection principle of *f-theta* lens and common lens, conversion rule from a fish eye image to a standard image is illustrated.

3.1 Conversion in Optical System

As shown in Fig.3, as for a $f\theta$ lens, product of the angle from optical axis θ [rad] and focal length f[mm] is equivalent to the height of length of the image l_f on screen. Namely,

$$l_s = f\theta \qquad (1)$$

This is illustrated further using Fig.4. As shown in this figure, product of ϕ is image angle, R is a diameter of image circle.

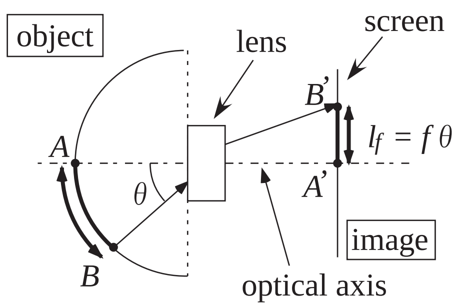


Figure 3: Principle of equidistance projection method

Let point A as an intersection of hemisphere side and optical axis as shown in the left figure of Fig.4. Then, the image of between of two points from the point A to arbitrary point B is given as shown in the right figure of Fig.4. From Equation (1), the height of length of the image lf for two points A' and B' is proportional to the θ. This means that in terms of the fish eye image it is possible to guess the angle from central point of image circle to arbitrary point easily as shown in the left figure of Fig.4.

As shown in Fig.5, as for a common lens, product of tangent of the angle from optical axis θ [rad] and focal length f[mm] is equivalent to the height of length of the image l_s on screen. Namely,

$$l_s = f\tan\theta \qquad (2)$$

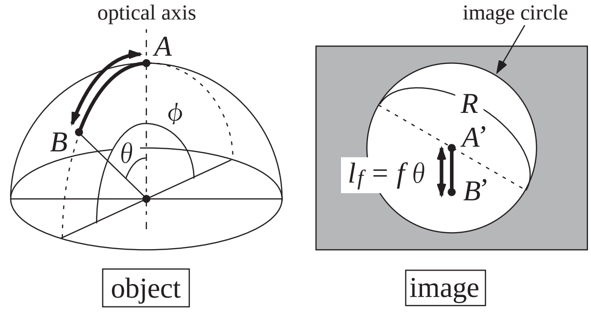


Figure 4: Projection of equidistance projection method

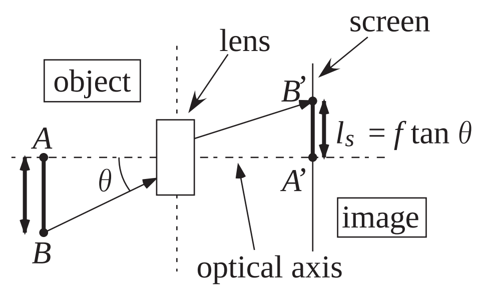


Figure 5: Principle of central projection method

3.2 Reverse Conversion

Consider an image conversion from fish eye image to standard image. A coordinates for standard image is determined based on a coordinates for fish eye image so that the origin of the coordinates for standard image corresponds to the one for fish eye image which is defined as a central point of image circle. The coordinates for each image is shown in Fig.6. In this case, coordinates value in standard image can be obtained as follows. First, calculate the angle from central point of image circle θ [rad] as shown Fig.4 from coordinates value A_f in fish eye image. Then, compute tangent of the θ. The $f\theta$ lens used in this paper can acquire the image of image angle 180 deg at the same time. However, the conversion for the coordinates balue of outside field of image circle and neighborhood of $\theta = \pm\pi/2$ rad cannot be performed. For instance, the conversion for $\theta = \pm\pi/2$ gives $\tan\pi/2 = \infty$. Thus, the converted coordinates value becomes infinite value. Therefore, consider the image conversion for the specified partial domain of original image.

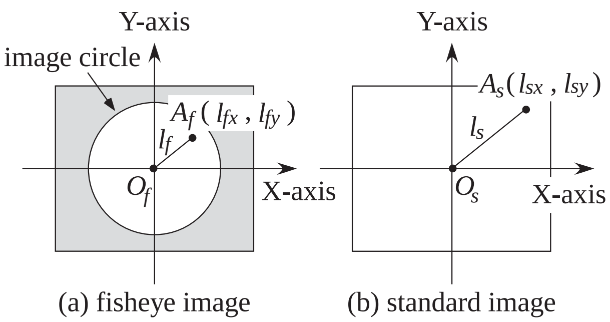


Figure 6: Conversion from fish eye image to standard image

3.3 Image Conversion Rule

In terms of the previous argument, provided that $f\tan\theta$ can be calculated from the measurement of $f\theta$ in fish eye image, it is possible to convert specified field of fish eye image into standard image.

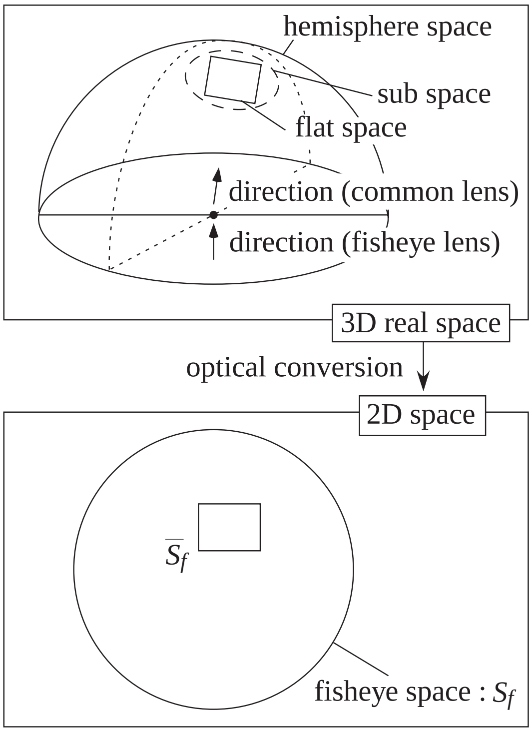


Figure 7: Space Conversion

In Fig.6, let point A_f be an arbitrary point in image circle of fish eye image and its coordinates value (l_{fx}, l_{fy}) be known. Then, consider an image conversion rule so that the coordinates value (l_{sx}, l_{sy}) of point A_s is determined. To this end, from the height of length of the image l_f for the straight line from central point of image circle O_f to the point A_f, calculate the height of length of the image l_s for its equivalence in standard

$$l_f = \sqrt{l_{fx}^2 + l_{fy}^2} \tag{3}$$

At this point, there is a relation of $1/f = \theta / l_f$ from a Equation(1). The following α is defined in consideration of the relation between ϕ and R shown in this and Fig.4.

$$\alpha = 1 / f = \phi / R \tag{4}$$

Thus, using Equation (4), distance l_s can be obtained as

$$l_s = \tan(l_f \alpha) / \alpha \tag{5}$$

Hence, the coordinates value (l_{sx}, l_{sy}) of the point A_s are given by Equation (6), (7) form the proportionality relation l_s is to l_f as l_{sx} is to l_{fx} and l_s is to l_f as l_{sy} is to l_{fy}.

$$l_{sx} = l_s \cdot l_{fx} / l_f \tag{6}$$
$$l_{sy} = l_s \cdot l_{fy} / l_f \tag{7}$$

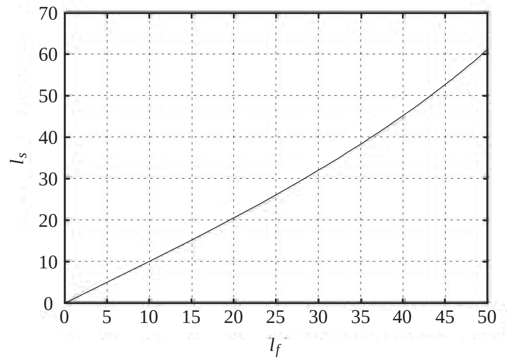


Figure 8: Graph of l_f v.s. l_s

4. INTERPOLATION OF CONVERSION IMAGE

In this study, CCD digital camera is used to capture fish eye images. The image conversion rule from fish eye image into standard image is illustrated in previous section. However, as explained in the following, there are some problems in the converted image by this rule.

4.1 Problems in Converted Image

Equation (5) is shown foundation principle of conversion under optical system. This conversion uses in digital space, so sparse problem is occurred. This is illustrated through an example.

In experiments, let a diameter of image circle R is 217 pixel, a range of θ is $-\pi/2 \sim \pi/2$ ($\phi = \pi$) rad. Using Equation (4), so α is = $\pi/217$ 1.45×10^{-2}[rad/pixel]. And l_f is specified follow lange, l_f = 0～51pixel. There values and magnitudes are typical values in common image processing. Fig.8 is shown graph that substitution of these values into Equation (5). This graph shown that ratio of l_f and l_s is approximately 1 in $0 < l_f < 15$, but l_s amounts to a value that (2) beyond one time l_f. Thus, distance of adjacent between two points on digital image space is 1, the distance may exceed 1 on digital image converted by Equation (5). Fig.8 shows this. Besides, so sparse problem that coordinates of convert points set at intervals is occurred not uncommonly, became used value is standard.

An interpolation algorithm to solve these problems is illustrated in the following.

4.2 Interpolation Algorithm

In this study, image interpolation is implemented using linear interpolation in the direction of a horizontal axis or vertical axis. Distinguishing the blank pixels p_{ij}*-bar* with no intensity data from pixels p_{li}, p_{ri}, p_{uj}, p_{bj} in which intensity data is given by conversion or interpolation. An arbitrary pixel tp_{ij}*-bar* among p_{ij}*-bar* is interpolated based on the information of pixels with intensity data p_{li} and p_{ri} or p_{uj} and p_{bj}, such an interpolation shown in Fig.9 is performed to the blank pixels. This is illustrated in the following.

Search pri, pli, puj, pbj pixels which intensity data in the right side and left side, up side and bottom side of an arbitrary pixel tp_{ij}*-bar* to respective pixels with intensity data are found (section L_{ri}, L_{li}, L_{uj}, L_{bj}) and there are determined as n_{li}, n_{ri}, n_{uj} and n_{bj}, respectively. Then, the distance between p_{li}-p_{ri} and between puj-pbj is defined as follows.

$$dif_{lr} = n_{li} + n_{ri} + 2 \tag{8}$$
$$dif_{ub} = n_{uj} + n_{bj} + 2 \tag{9}$$

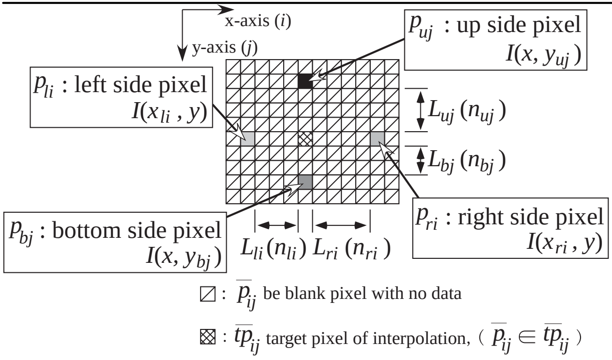


Figure 9: Interpolation algorithm

The distance of dif_{lr} and dif_{ub} is compared and tp_{ij}-*bar* is interpolated in the short direction. Moreover, when pixel with intensity data does not exists in neither of right side and left side, horizontal interpolation does not carry out but only vertical interpolation is performed. Similarly, only horizontal interpolation id performed when pixel with intensity data does not exist in either of upside and bottom side.

The intensity data given to tp_{ij}-*bar* is determined as follows. In Fig.7, if compared dif_{lr} and dif_{ub}, since vertical interpolation will be chosen, an example is given and the case of vertical interpolation is explained follows. Let intensities of p_{uj} be $I(x, y_{uj})$ and p_{bj} be $I(x, y_{bj})$. In the case where the values of intensity $I(x, y_{uj})$ and $I(x, y_{bj})$ are different, interpolation is performed to the blank pixels so that the blank pixel may change gradually. In the case where the values of intensity $I(x, y_{uj})$ and $I(x, y_{bj})$ are same, then interpolates $I(x, y_{uj})$ or $I(x, y_{bj})$ to the blank pixels. Specifically, let D_i be the difference between the intensities $I(x, y_{uj})$ and $I(x, y_{bj})$ and γ be gradual variable, and define as follows.

$$D_j = I(x, y_{uj}) - I(x, y_{bj}) \quad (10)$$

$$\gamma = D_i / dif_{ub} \quad (11)$$

The interpolation follows the following algorithm. In addition, let intensities of tp_{ij}-*bar* be $I(i, j)$.

- In the case where the intensities of $I(x, y_{uj})$ and $I(x, u_{bj})$ are different ($D_i \neq 0$)

$$I(i, j) = I(x, y_{uj}) + \gamma \cdot (n_{uj}+1) \quad (12)$$

- In the case where the intensities of $I(x, y_{uj})$ and $I(x, u_{bj})$ are same ($D_i = 0$)

$$I(i, j) = I(x, y_{uj}) \quad (13)$$

The procedure is repeated to the right end of the converted image, then move to the next vertical axis line. Moreover, horizontal interpolation is performed like vertical interpolation.

5. EXPERIMENTS

Using the image conversion rule proposed in section 3.3, image conversion from fish eye image into standard image is performed. A square field is selected as a partial domain. Since sparse problem arises only by applying the conversion in section 3.3, the interpolation proposed in section 4.2 is applied to the converted image.

5.1 Image Conversion

In the experiments, for simplicity square field whose length in every direction is 51 pixels in fish eye image is chosen as a partial domain. Let image angle of used fish eye lens ϕ was π rad, diameter of image circle R was 217 pixels. The central point of image circle, in other word origin of the coordinates of fish eye image, is known due to the previous measurement.

As the first stage, conversion of gray-scale image is implemented. To this end, original color image in fish eye image is converted to gray-scale image in advance, which means that the intensity data is also given in black-and-white.

Experimental result of the conversion from fish eye image into standard image are shown in Fig11, where figure (a) is an original image in fish eye image, figure (b) is the converted image in standard image. From the figures of these experimental results, as explained in section 4.1, it turns out that there exist blank pixels with no intensity data and crevice is generated in the converted image in standard image. Besides, it is confirmed that as separating from the origin of fish eye image, the distance between adjacent pixels with intensity data becomes large.

5.2 Interpolation of Converted Image

In order to solve above problem, the interpolation algorithm stated in section 4.2 is applied to the converted image.

Experimental results of the interpolation to the converted image is shown in Fig.11, where figure (b) is the converted image in standard image before interpolation and figure (c) is the interpolated image in standard image.

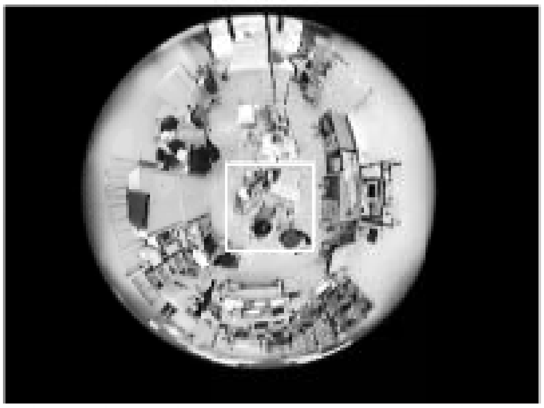
In comparison with Fig.11 (b), surrounding situation is appeared in Fig.11 (c). Moreover in fish eye image, the part was being distorted (the upper right of image circle of Fig11 (a)) has been confirmed that became straight line in converted image (the right of Fig11(c)). Hence, it can be said that the original image is converted to the perspective image.

In the former, gray-scale image was converted. As the second stage, conversion of color image is performed. The same techniques as gray-scale image for conversion and interpolation is applied to Red, Green and Blue in color image respectively. Experimental results of the image conversion for color image are shown in Fig11. As seen in these figures, also in the color image, surrounding situation can be fully recognized as well as gray-scale image.

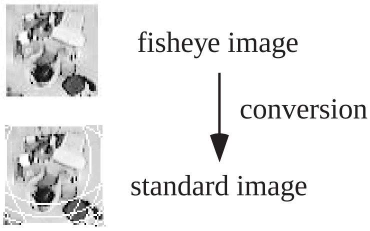
As compared with the converted image with no interpolation, surrounding situation becomes clear in the interpolated image.

5.3 Operation experiment of proposed system

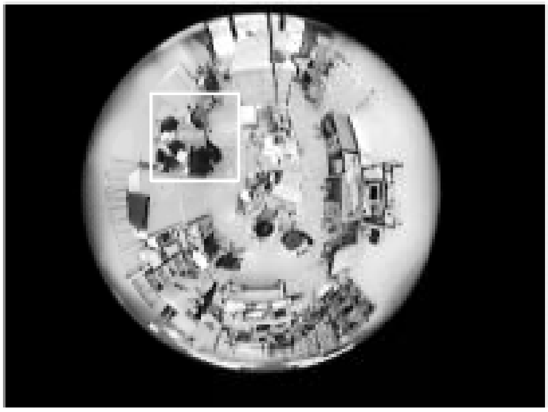
The new observation system shown in Fig.1 was built combining the image conversion part and the vision part. However, since PC is used, the picture conversion per flame takes about 2～3 seconds. On the other band, head motion takes 300 deg/sec at the maximum speed. There fore, only late head operation can be followed in this system. However, this problem is solvable with creation of the exclusive processing board of image conversion.



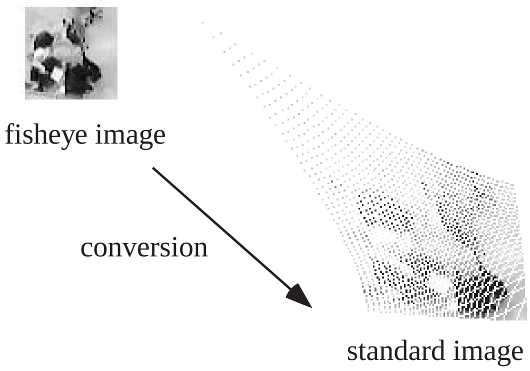
Coordinates of central point of selection range : (3, -7)



(a) example of conversion 1

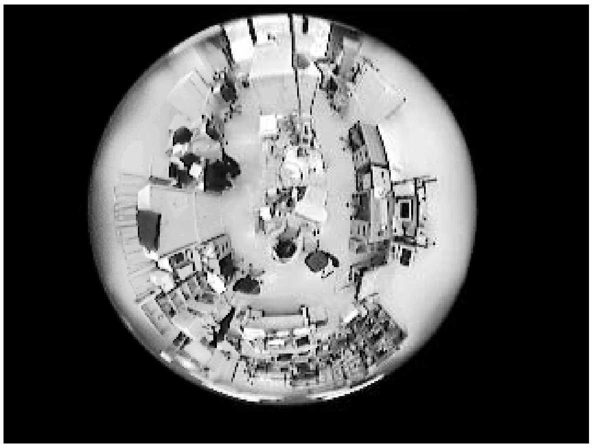


Coordinates of central point of selection range : (-43, 35)

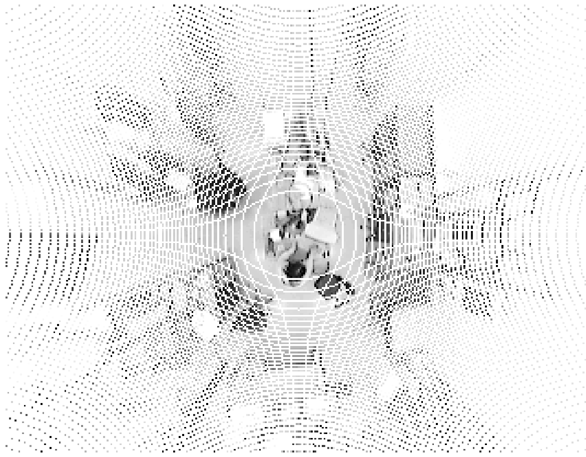


(b) example of conversion 2

Figure 10: Results of conversion for gray-scale image



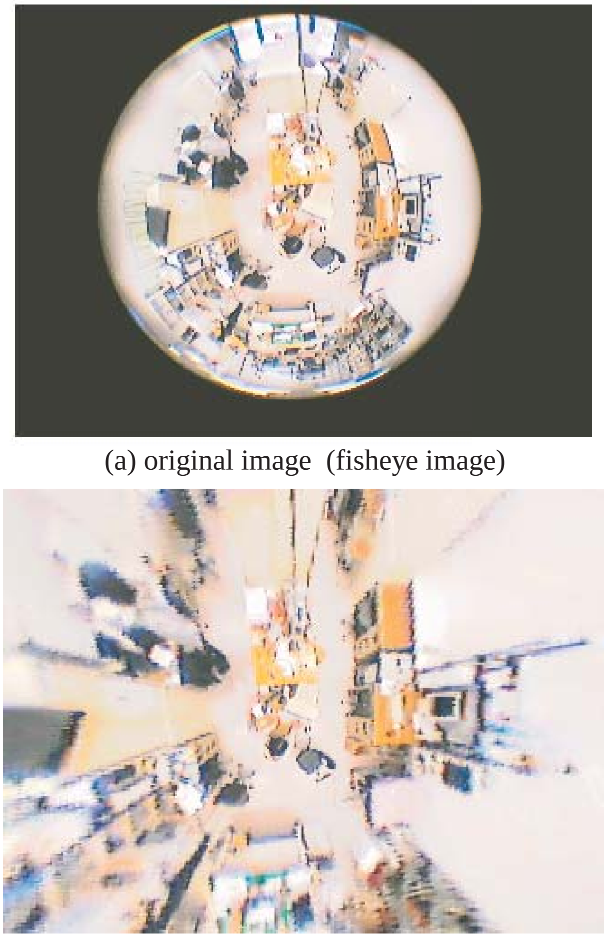
(a) original image (fisheye image)



(b) converted image
(standard image : before interpolation)

(c) crosswise interpolated image (standard image)

Figure 11: Results of interpolation for the converted gray-scale image



(a) original image (fisheye image)

(b) interpolated image (standard image)

Figure 12: Results of interpolation for the converted color image

6. CONCLUSIONS

In this paper, new observation system is proposed and fish eye lens was taken up for omni-directional image sensing. The image conversion rule from fish eye image into standard image is proposed, and it was applied to the real image. However sparse problem was occurred due to the treatment of the digital data. To solve this problem, the interpolation algorithm for the pixels with no intensity data is proposed and it was applied to the converted image. As a result the perspective images were obtained for both gray-scale and color images.

Moreover, since the processing time of image conversion is late, new observation system has a problem that the image which followed head motion cannot be displayed. This problem is solvable by creating the hardware which image conversion is processed on an exclusive processing board.

REFERENCES

[1] S.K.Nayar, "Omnidirectional vision", *Proc. of British Machine Vision Conference*, pp. 1-12, 1998.

[2] Y.Yagi, "Omnidirectional Imaging", *Technical Report of IEICE*, 1997 (in Japanese).

[3] H.Tanahashi, D.Shimada, K.Yamamoto and Y.Niwa, "Acquisition of Three-Dimensional Information in a Real Environment by Using The Stereo Omnidirectio nal System (SOS)", *proc. of the Third International Conference on 3-D Imaging and Modeling (3DIM2001)*, pp. 365-371, 2001.

[4] K.Yamamoto, H.Tanahashi, S.Kuwasima and Y.Niwa, "Sensing of Real Environment by Stereo Omnidirecti onal System (SOS)", *Transactions of IEE Japan*, Vol. 121-C, No.5, pp.876-881, 2001. (in Japanese)

[5] Y.Yagi and N.Yokoya, "Omnidirectional Vision A S urvey on Sensors and Applications", *IPSJ Transacti ons on Computer Vision and Image Media*, Vol.42, No.SIG12-003, 2001. (in Japanese)

[6] http://www.suekage.com/

[7] R.Mori and F.Miyazaki, "Examination of Ball Catch ing Strategy through Autonomous Mobile Robots", *Transactions of the Society of Instrument and Contr ol Engineers*, Vol.38, No.6, pp.543-548, 2002. (in J apanese)

[8] N.Watanabe, "Reconstruction of 3-Dimentional Mode l From Equi-Distance (f-θ) Fish-Eye Images", *Proc. of the 8th Symposium on Sensing Via Image Inform ation*, pp.389-394, 2002. (in Japanese)

[9] http://www.movingeye.co.jp/

[10] http://www.root.or.jp/fit/

[11] http://www.nec-tokin.com/