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ACCURACY OF MEASUREMENT USING A PAIR OF STEREO IMAGES ACQUIRED BY FINEPIX REAL 3D W1 WITHOUT CONTROLS

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ABSTRACT:

The consumer digital stereo camera; FinePix REAL 3D W1 was released by FUJIFILM Cooperation in August, 2009. Since REAL 3D W1 was designed to take a pair of stereo images for stereo viewing, the baseline length of 77 mm of the camera is unsuitable for accurate stereo measurement. The aim of our study is to evaluate the accuracy of measurement using a pair of stereo images acquired by REAL 3D W1 without any controls. We evaluated the accuracy of 3D measurement with three parameter sets. The first parameter set was extracted from the obtained image file, the second one was obtained by camera calibration, and the third one was estimated by using a pair of stereo images depicting a scale. Since an image file has no information about digital zooming, the obtained image file cannot provide a reasonable measurement result without any additional information. Meanwhile, the camera calibration would enable to measure dimensions of an object with the accuracy equivalent to the expected accuracy calculated by following the rules of error propagation.

1. INTRODUCTION

Digital devices for photographs and movies are evolving remarkably in recent years. It is saying that the device of taking a picture brings miniaturization, high resolution, and cheapness. And about viewing device, 3D pictures have been becoming familiar. The consumer digital stereo camera; FinePix REAL 3D W1 was released by FUJIFILM Cooperation in August, 2009. The camera is able to take 3D pictures very easily. Therefore, in this study, we evaluate the camera's accuracy of 3D measurement. The maker of the camera published that the purpose of the camera is to take 3D images for pleasure. That is to say, it does not consider about accuracy. We intend to measure dimensions of an object on a sub-meter scale by using a pair of stereo images acquired by the REAL 3D W1 camera without any controls.

The aim of our study is to evaluate the accuracy of measurement using a pair of stereo images acquired by REAL 3D W1 without any controls. Therefore, the research of applied possibility on this camera to the measurement might be very useful.

(a) Front (b) Backside

Figure 1. Exterior view of FinePix REAL 3D W1

2. FINEPIX REAL 3D W1

Figure 1 shows the exterior of the camera. Two lenses are loaded at the front, and liquid-crystal display is loaded at the back. We can see a 3D image at the display without special tools, such as glasses. Table 1 shows the main features of the camera.

Model	FinePix REAL 3D W1
Number of effective pixels	10.0 million pixels
Unit cell size on the focal plane	1.68 μm × 1.68 μm
CCD sensor	1/2.3-inch CCD x2
File format	3D Still image: MPO + JPEG, MPO (Multi Picture Format compatible)
Number of recorded pixels	3,648 × 2,736 pixels
Lens	Fujinon 3x optical zoom lens, F3.7(W) - F4.2(T)
Base line length	77mm
Focal length	f = 6.3 - 18.9 mm, equivalent to 35.0 - 105.0 mm on a 35 mm camera
Zoom	up to 3.8x (Combined optical and digital zoom)
Distance to congested point	Wide: Approx. 2 m Telephoto: Approx. 6.5 m
Convergence angle	2.2 degree
Dimensions	Approx. 123.6 (W) × 68 (H) × 25.6 (D) mm

Table 1. Specifications of 3D mode of FinePix REAL 3D W1

We can take not only 3D pictures but also 2D pictures with FinePix REAL 3D W1. We can not use the right lens of the camera in the 2D mode. 3D pictures are saved in a MP (Multi-Picture) format file. This format is a format extended from Exif (Exchangeable Image File Format) for storing multiple, associated images in a single image file (CIPA, 2009). The format can store not only multiple still images but also associated metadata such as a convergence angle and a baseline length in a single file.

“Point of convergence” in Table 1 means the point where the optical axes of the two lenses intersect and parallax disappears according to the owner’s manual of the REAL 3D W1 camera.
“Convergence Angle” is defined as the angle formed by the first line of sight from the base viewpoint and the line which is the vertical projection of the second line of sight from the other viewpoint onto the plane containing the first line of sight.
“Baseline Length” is defined as the distance between two viewpoints.

We can divide a MP file to two Exif files by using the viewer soft; FinePix Viewer which is attached to the camera. Figure 2 shows the example of divided Exif files.

This camera has optical and digital zoom function. Figure 3 shows comparing the 3D image and the 2D image which was taken from the same position and with the same focal length setting.

These images are not the same. In the 2D mode, optical and digital zoom are not performed at once (digital zoom performed at last). On the other hand, in the 3D mode, optical and digital zoom are performed at once. The camera records no information about digital zooming.

3. ACCURACY OF MEASUREMENT

3.1 Theory

Two lenses on this camera are fixed hardly, and the baseline length and the convergence angle are given. Therefore, one can measure dimensions of an object without any controls. However, the location of the projection centre is unknown without exterior orientation. In this study, we conducted measurement of the object dimensions.

Parameters such as the baseline length, the convergence angle, the location of the principal point, the focal length, the radial distortion coefficients and the decentering distortion coefficients were obtained by three methods in this study. The equation of geometric displacement model (J. G. Fryer, 1996) is given:

$$\Delta x = x_0 + \frac{\bar{x}}{r}(k_0 r + k_1 r^3 + k_2 r^5) + p_1(r^2 + 2x^2) + 2p_2 xy \quad (1)$$
$$\Delta y = y_0 + \frac{\bar{y}}{r}(k_0 r + k_1 r^3 + k_2 r^5) + p_2(r^2 + 2y^2) + 2p_1 xy$$

$\bar{x}, \bar{y}$ are the photogrammetric coordinates from the principal point, and given:

$$\bar{x} = x - x_0 \quad (2)$$
$$\bar{y} = y - y_0$$

r is distance from the principal point for the photogrammetric coordinate, and given:

$$r^2 = \bar{x}^2 + \bar{y}^2 \quad (3)$$

Where $\Delta x, \Delta y$ are the geometric displacement, x, y are the photogrammetric coordinates, x_0, y_0 are the principal point, k_0 is the coefficient about the focal length, k_1, k_2 are the radial distortion coefficients, and p_1, p_2 are the decentering distortion coefficients.

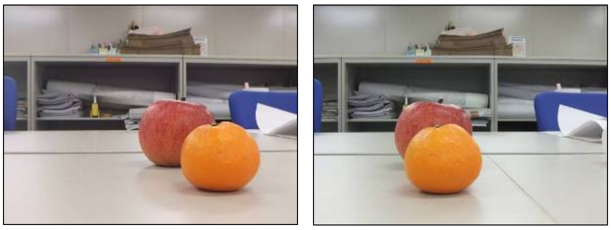
3.2 Calculate of parameters

3.2.1 From the MP file

The baseline length, the convergence angle, and the focal lengths are given in the MP file. The other parameters such as the location of the principal point, radial distortion coefficients, and decentering distortion coefficients are out of consideration. We assumed that amateur users are using this method.

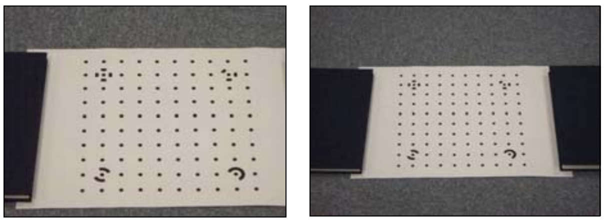
3.2.2 By the camera calibration

Images used in the calibration were taken at four directions and eight pose using the calibration grid as Figure 4 shows. Calibration software is PhotoModeler Pro 5 which was developed by Eos Systems Inc.



(a) Left image (b) Right image

Figure 2. A pair of stereo images taken in the 3D mode



(a) 3D image by the left lens (b) 2D image by the left lens

Figure 3. 3D and 2D images

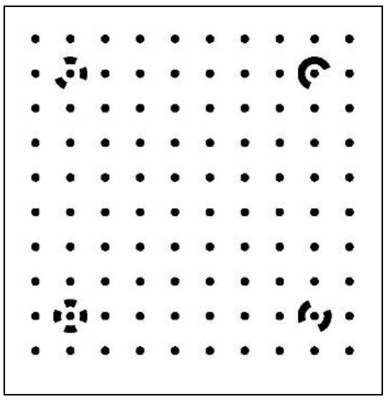


Figure 4. Calibration Grid

The focal length, the location of the principal point, the radial distortion coefficients, the decentering distortion coefficients, the projection center, and the rotation angle are given by the result of camera calibration.

The baseline length and the convergence angle were calculated by right and left projection center and rotations. The rotation angle related rotation vector. Calculating dot product of it is deriving the convergence angle. We assumed that professional users are using this method.

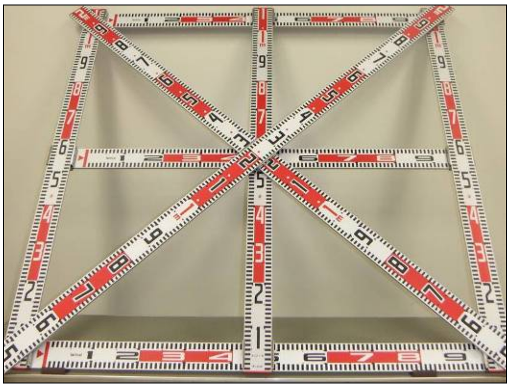
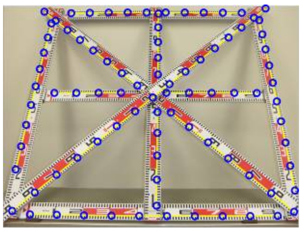
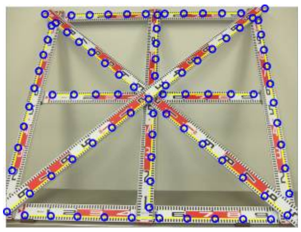


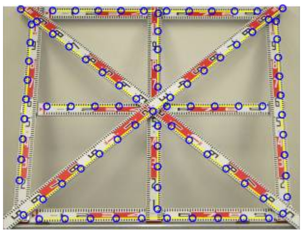
Figure 5. Measured object



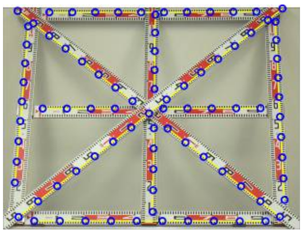
(a) *f* = 6.3 mm [Left]



(b) *f* = 6.3 mm [Right]



(c) *f* = 18.9 mm [Left]



(d) *f* = 18.9 mm [Right]

Figure 6. Images utilized in the measurement

		Points	Line segments	
Horizontal	Top	10	9	
	Centre	9	7	
	Bottom	10	9	25
Vertical	Left	9	8	
	Centre	10	8	
	Right	10	9	25
Diagonal	TR – BL	15	13	
	TL – BR	16	15	28

Table 2. Numbers of the points and line segments utilized for the evaluation of the measurement accuracy

3.2.3 By using from measuring distance

Parameter is calculated by distance from the lens to the object and the object size on a photograph. We assumed that semi-professional users are using this method.

3.3 Measurement

Evaluate the accuracy of these three method's parameter. Figure 5 is a photograph of an object which used at the experiment.

Locations of 89 points on three horizontal lines of 100 cm long, three vertical lines of 100 cm long and two diagonal lines of 160 cm long were measured.

A Pair of stereo images was taken obliquely at an angle of approximately 36 degrees. The distance from the camera to the target varied according to the focal length as unit cell size on the target so that each image scale was nearly equal. Figure 6 shows some images utilized in the measurement.

78 measurement results of the lengths of line segments were utilized for the evaluation of the measurement accuracy. Table 2 shows the number of points whose locations were measured and the number of line segments whose lengths were estimated.

TR - BL and TL - BR in Table 2 mean that the line segment is located at the top right to the bottom left, at the top left to the bottom right of the lattice respectively.

Locations of endpoints of line segments were measured by the cross correlation method and the same images coordinates of endpoints were utilized in the evaluation of the measurement accuracy.

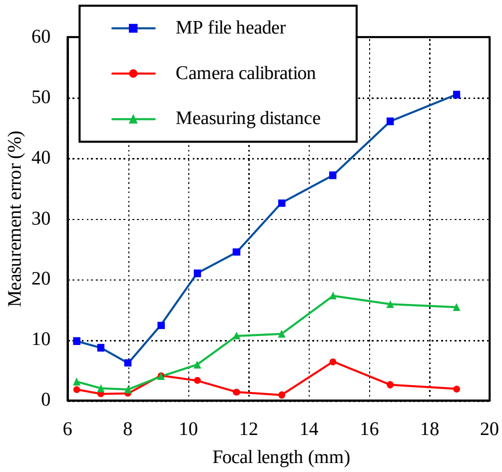
3.4 Results and discussion

The result of comparing the distance accuracy shows in Figure 7. All of measurement accuracies by the MP file, camera calibration and measurement became worse as the focal length increased. Finally, the error is more than 50% and low from true value. It means that calculated value is 5cm though true value is 10cm. This result shows that the MP file includes any error factors.

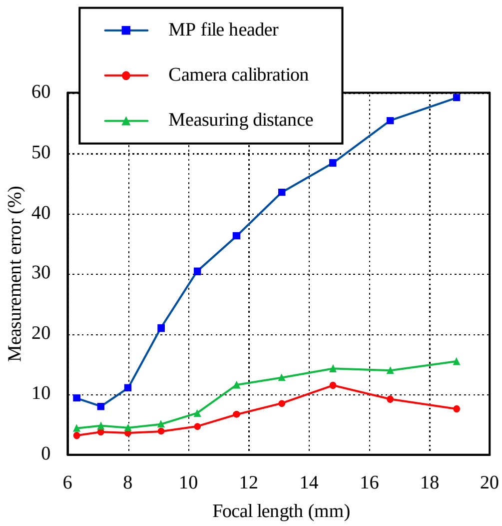
The measurement accuracy by MP file in particular declined. The reason should be that the disparity between the principal distance and the nominal focal length became larger and the displacement of the centre of the zoomed area form the centre of the CCD became larger as the focal length increased. We concluded that the measurement by MP file using the REAL 3D W1 camera of the focal length larger 8.0 mm should be undesirable.

By measuring distance method obtained rather good measurement results except diagonal line segment. Although by camera calibration obtained the best measurement results, one would consider that the measurement accuracy by camera calibration could be unsatisfactory.

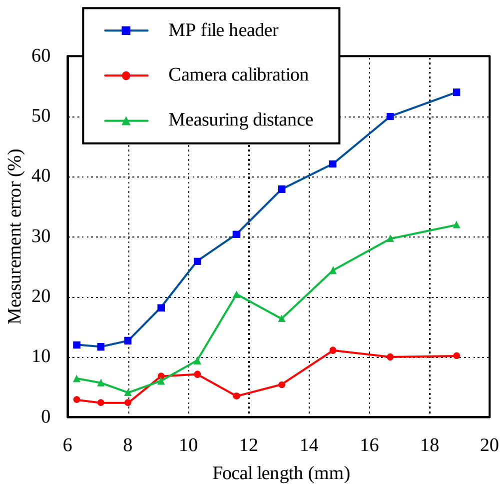
The results of Figure 7 shows that the measurement error from the MP file is remarkably high. We discussed about that at chapter four.



(a) Horizontal



(b) Vertical



(c) Diagonal

Figure 7. Measurement error

4. ANALYSIS ON LOW ACCURACY OF MEASUREMENT -

It is appear that the MP file includes any error at chapter three. In this chapter, we disclose the parameter which includes error. We verify focal length, principal point and convergence angle respectively.

4.1 Compare parameter value

Table 3 shows parameter value and probability of calculation each method.

4.2 Focal length

We compare focal length. We use four methods which add a new method to three methods at chapter three.

Method 1: From the MP file.
Method 2: By camera calibration.
Method 3: By measuring distance.
Method 4: From comparing 2D and 3D images.

Figure 8 shows comparing result. It can be seen from this figure that values of Method 2-4 are more than the MP file's value. These three methods are the almost same value. Therefore, it is expected that the focal length in the MP file is improper for measurement. Because, as already described, digital zoom factor is not saved in the MP file at 3D images. (Only the optical zoom factor is saved.) And it can be seen in this figure that the digital zoom factor is approximately 1.1 – 1.4.

Parameter	Value from specification	MP file	Camera calibration
Baseline length	77 mm	Yes (77 mm)	Yes
Principal point	-	No(*1)	Yes
Focal length	f = 6.3 - 18.9 mm, equivalent to 35.0 - 105.0 mm on a 35 mm camera	Yes	Yes (Calculate with digital zoom)
Digital zoom scale	Approx. 5.7 times (max)	No(*2)	
Convergence angle	-	Yes (2.2°)	Yes (Indirectly)
Distance to congested point	Wide: Approx. 2 m Telephoto: Approx. 6.5 m	No(*1)	Yes (Indirectly)
Radial lens distortion / Decentering distortion	-	No(*1)	Yes

Table 3. Parameter value and probability of calculation each method

*1: Because a tag for the parameter is not defined, any camera cannot store a value of the parameter in a MP file.
*2: Tag is defined. Although the tag for the parameter is defined the camera does not store a value of the parameter in a MP file.

4.3 Horizontal displacement of principal point

The principal point is not the location of the record in the MP format file. Accordingly, we put the principal point on the image centre. On the other hand, by camera calibration, the principal point was calculated because we assumed that the parameter was unknown. Figure 9 shows the horizontal displacement of principal point with camera calibration. Positive direction is right direction on a photograph.

The result shows that the displacement of the principal point is increase as the focal length increased. That is probably to say, centre of digital zoom area is change with the focal length in order to human stereo viewing. Accordingly, this result shows that the convergence angle is changes as the same.

5. EVALUATION OF THE MEASUREMENT ACCURACY

The results of Figure 9 shows are looks like very low accuracy. Therefore, we calculated the measurement accuracy and the expected accuracy from images coordinates one with using equation of error propagation. Additionally, we compared to the expected accuracy with the measured accuracy by camera calibration.

5.1 Theory

Object coordinate (*X, Y, Z*) has been calculated with the Equation (4).

$$\begin{cases} X = \dfrac{c\cos\dfrac{\theta}{2} + x_R \sin\dfrac{\theta}{2}}{\left(c^2 + x_L x_R\right)\sin\theta + c\left(x_L - x_R\right)\cos\theta}\left(c\sin\dfrac{\theta}{2} + x_L\cos\dfrac{\theta}{2}\right)B \\ Y = \dfrac{c\cos\dfrac{\theta}{2} + x_R \sin\dfrac{\theta}{2}}{\left(c^2 + x_L x_R\right)\sin\theta + c\left(x_L - x_R\right)\cos\theta} yB \\ Z = \dfrac{c\cos\dfrac{\theta}{2} + x_R \sin\dfrac{\theta}{2}}{\left(c^2 + x_L x_R\right)\sin\theta + c\left(x_L - x_R\right)\cos\theta}\left(c\cos\dfrac{\theta}{2} - x_L\sin\dfrac{\theta}{2}\right)B \end{cases} \qquad (4)$$

Where, (x_L, y) and (x_R, y) are the object relative coordinates from the principal point on the left and right image respectively, θ is the convergence angle, B is the baseline length, and c is the principal distance.

We assumed that left and right projection centres are (0, 0) and (B, 0). Additionally, the principal distance (c) and the vertical reading error on both images are equal. And positive directions on images are right and up.

5.2 Results and discussion

We calculated the expected accuracy by using the rules of error propagation in order to evaluate the measurement accuracy by camera calibration. Since the locations of the endpoints of the line segments were measured by the cross correlation method, the standard deviation of the measurement error on the image was assumed to be $1/\sqrt{12} \approx 0.289$ pixels. Figure 10 shows the comparison between the expected accuracy and the measured accuracy by camera calibration. T-L, C-C, and B-R in Figure 10 mean that the line segment is located at the top left, the centre and the bottom right of the lattice respectively.

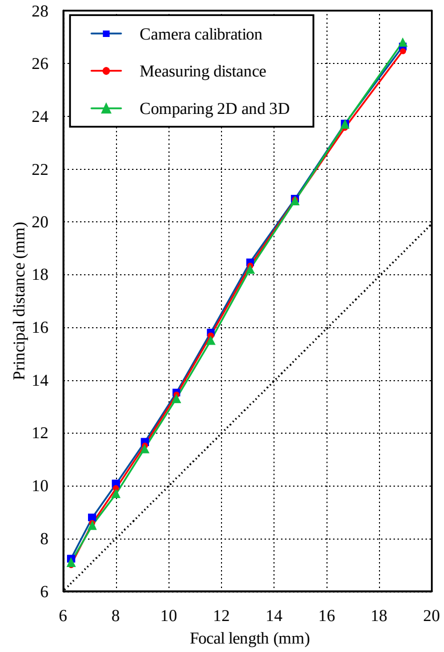


Figure 8. Estimated Principal distance

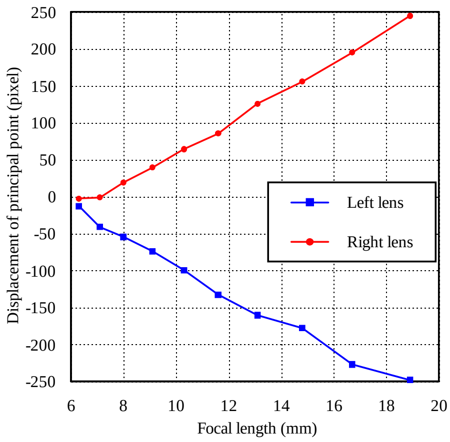


Figure 9. Displacement of principal point (Horizontal)

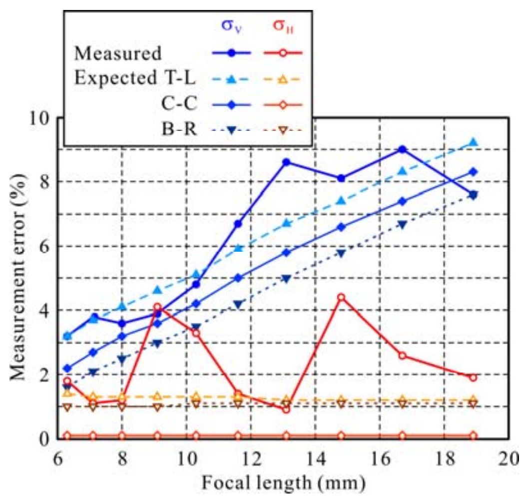


Figure 10. Measurement accuracy by the camera calibration and expected accuracy

Figure 10 shows that the measurement accuracy by camera calibration was lower than the expected accuracy for some focal lengths. The low measurement accuracy would be caused by the image quality that some parts of the image were somewhat out of focus as Figures 11 and 12 show. Figures 11 and 12 show an out of focus part and an in focus part on the horizontal lines of f = 14.8 mm, and an out of focus part and an in focus part on the vertical lines of f = 13.1 mm respectively.

Figure 10 shows that the reasonably accurate measurement by using the REAL 3D W1 camera requires appropriate camera calibration. Results of the measurement by using parameters results obtained by the appropriate camera calibration should be acceptable.

6. CONCLUSION

- We evaluated the accuracy of 3D measurement with three parameter sets. The first parameter set was extracted from the obtained image file, the second one was obtained by camera calibration, and the third one was estimated by using a pair of stereo images depicting a scale.

- No information about digital zooming is recorded in an image file acquired by FinePix REAL 3D V1. Therefore, the measurement only using the information recorded in the acquired image file is inaccurate.

- The camera calibration would provide measurement results of 10% error at the most. If we can accept this measurement accuracy, FinePix REAL 3D W1 would be very easy and useful for 3D measurement.

- We calculated the expected accuracy by following the rules of error propagation in order to evaluate the measurement accuracy. As a result, the measurement accuracy by using the parameter set obtained by camera calibration would be almost equivalent to the expected accuracy.

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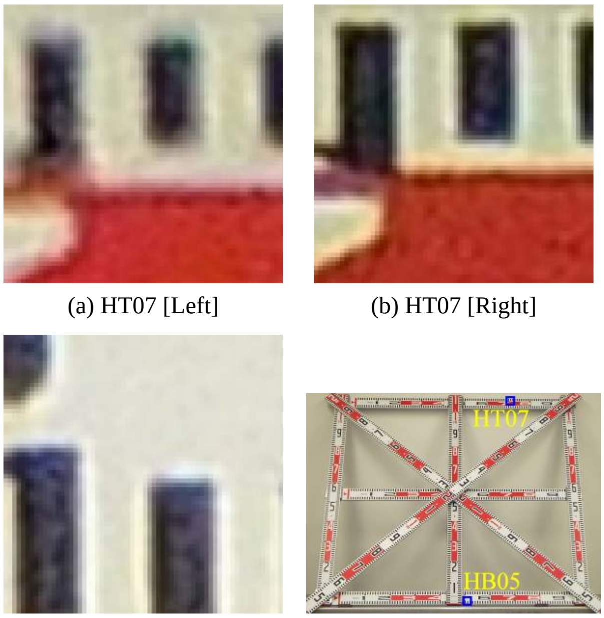
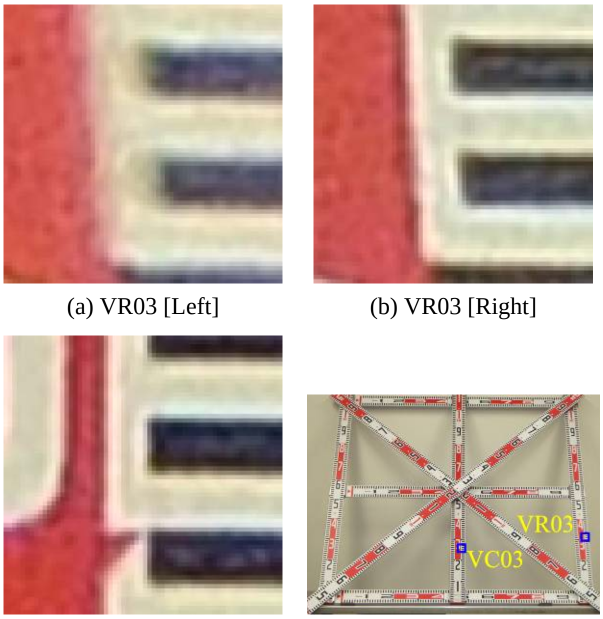


(a) HT07 [Left] (b) HT07 [Right]

(c) HB05 [Left] (d) Left image

Figure 11. Out of focus part on the horizontal line of the image utilized in the measurement (f = 14.8 mm)



(a) VR03 [Left] (b) VR03 [Right]

(c) VC03 [Left] (d) Left image

Figure 12. Out of focus part on the vertical line of the image utilized in the measurement (f = 13.1 mm)