Suggestion of geometric correction to measurement of Fried's Parameter by DIMM

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Abstract—In this paper, effect of atmospheric turbulence and the measurement method of Fried's parameter r_0 that is needed to evaluate the turbulence are summarized. We tried the measurement of Fried's Parameter using DIMM (Differential Image Motion Monitor) method. But the influence of extension of the image by having used a prism is seen in the measurement result. So we propose geometric correction and inspect its validity of the correction.

*Keywords—***free space laser communications, atmospheric turbulence, DIMM, Fried's Parameter.**

I. INTRODUCTION[1][2]

Year by year, satellite sensor has become high resolution and wide observation breadth, and communication traffics tend to increase. We regard optical communication as the technology to deal with large-capacity data. But, in order to put optical communication into practice, there are some difficulties such as interception by clouds and atmospheric turbulence. When light propagates space with the atmosphere, angle of arrival fluctuation is caused by the changes of the random refractive index, absorption and dispersion. Angle of arrival fluctuation causes attenuation or fluctuation of receiving power and beam spot dancing. This effect may cause deterioration of the communication quality.

Against that, we can take countermeasures to reduce the influence of the fluctuation by measuring atmospheric coherence length (Fried's Parameter).

In this report, we use DIMM method to measure Fried's Parameter. But, the influence of extension of the image by having used a prism is seen in the measurement results. So we perform geometric correction introduced to the data obtained by experiment and inspect its validity of the correction. As a result, we show that we can measure a value of appropriate Fried's Parameter by using this correction.

II. DIMM

DIMM is one of the methods to measure Fried's Parameter. Fried's Parameter is defined that the root mean square phase distortion over a circular of diameter of r_0 is about 1 radian[3]. Figure 1 shows DIMM's mechanism. We attach a mask with some apertures covered with an optical prism to the front of the telescope and install CCD camera behind them. Table 1 shows specifications of the telescope. Observing a light source through this instrument, the light arrives on a telescope is refracted by a prism and we obtain two images from one light source. Atmospherically distorted wave fronts are detected by two images. By calculating variance of relative position of each centroid σ, we can find Fried's Parameter.

From a condition of the size of aperture, this DIMM can measure correctly when Fried's Parameter is 3cm ~ 7cm.

We can calculate for two directions (see Figure 2). One is longitudinal direction that is parallel to direction between apertures (direction L). Another is transverse direction that is perpendicular to direction between apertures (direction T). The equations written as[4]

$$\sigma_L^2 = 2\lambda^2 r_{0_L}^{-3/5}\left(0.179D^{-1/3} - 0.0968d^{-1/3}\right) \qquad (1.1)$$

$$\sigma_T^2 = 2\lambda^2 r_{0_T}^{-3/5}\left(0.179D^{-1/3} - 0.145d^{-1/3}\right) \qquad (1.2)$$

where σ_L is the variance of relative position of each centroid of longitudinal direction, σ_T is that of Transverse direction, r_{0_L} is Fried's Parameter of longitudinal direction, r_{0_T} is that of transverse direction, d is distance between apertures, D is mask aperture diameter and λ is wave length.

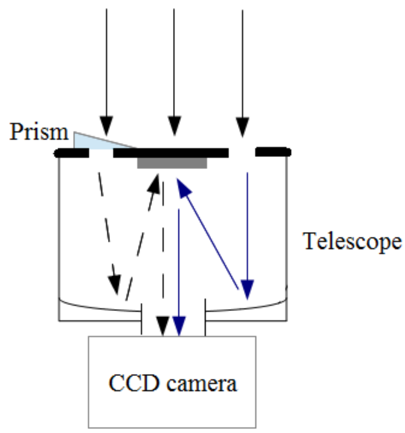


Figure 1. DIMM mechanism.

Broken lines show the path that refracted light goes through. If we do not use a prism, the light that passed each aperture reflects an image in the same place, that is to say one image. But, in setting up a prism and refracting unilateral light, we can separate two images.

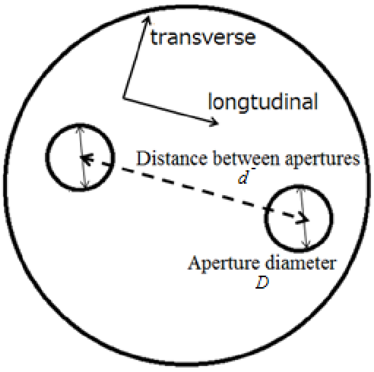


Figure 2. Shape of the mask with two apertures

Table 1. Specifications of telescope and mask

Telescope aperture	100 mm
Focal length	800 mm
Mask aperture diameter *D*	20 mm
Distance between apertures *d*	80 mm
Prism vertical angle	0.5 deg

III. EXPERIMENT AND RESULT

We observed the polestar from National Institute of Information and Communications Technology (NICT), Koganei. We installed experimental equipment so that the direction between apertures became level to the ground.

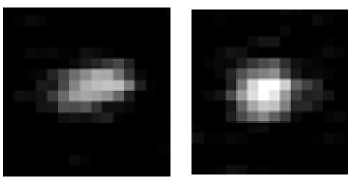
A. Image Extension

It became clear that the image that was made by the light that passed a prism was extended to the direction where light is refracted by the prism(see Figure 3). So, the variation of the centroid position was enlarged apparently. Due to this effect, Fried’s Parameter of the horizontal direction that is the direction between apertures became small.

In this experiment, I used the prism for only one aperture. So we try to think about the case that not used prisms and used two prisms on each aperture.

When we do not use prisms either, we cannot separate each images.

And, when we set up a prism for each aperture, because of difference in the vertical angle of each prism, two images are enlarged in a different ratio. So, just because we set up two prisms, we cannot measure an accurate Fried's Parameter.



(a) **(b)**

Figure 3. Expanse of the image.

(a): The image that was made by the light refracted. We can find the expanse of the image.

(b): The image that was made by the light that went straight on.

B. Geometric Correction Method

Therefore, to try revision, we make another mask that has three apertures and their directions between apertures are at right angles. We observe each direction by different combination of apertures at the same time (see Figure 4). We set up a prism in aperture A and C.

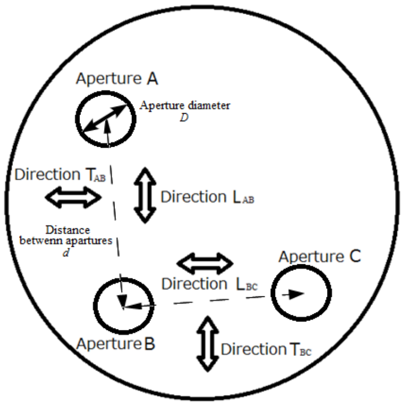


Figure 4. Shape of the mask with three apertures.

Table 2. Specifications of mask with three apertures

Mask aperture diameter *D*	20 mm
Distance between apertures *d*	5.65 mm
Prism vertical angle	0.5 deg

As shown in Figure 4, Fried’s Parameter of direction T observed in aperture A and B at the position of the top and bottom and that of direction L observed in aperture B and C at the position of right and left are should become the about the same value, because we observe the neighboring same direction. So, we try revision to this observation result, and inspect validity of the correction.

Table 3 . Image size

Normal		Through a prism	
Width W_N	Height H_N	Width W_P	Height H_P
6.417 pix	5.076 pix	7.613 pix	4.233pix

We found that the size of length and breadth changed like a Table 3 whether light passed a prism. And, reduction in light quantity to transmit causes the reduction of the height of image(See Table 4). After comparing the maximum of the brightness of each image, the image of the aperture where set up a prism tended to be a small value.

Table 4. Total of the brightness level of image

	Normal	Through a prism
total of the brightness level of image	3033	2400

In adding revision so that this aspect ratio becomes the same value, we may give revision to the enlarged centroid fluctuation of the image.

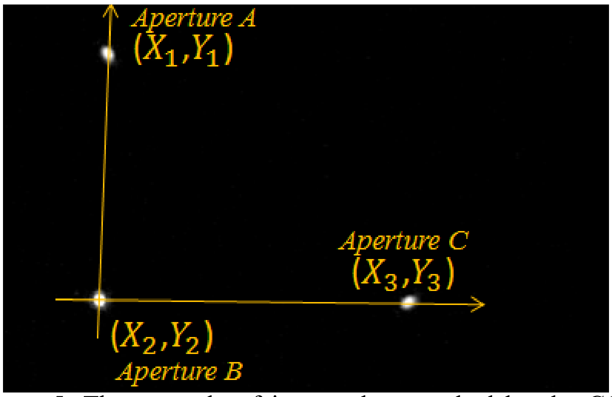


Figure 5. The example of image photographed by the CCD camera.

We set up a prism in aperture A and C. By a prism installing in aperture C, the light is refracted laterally, and by that installing in aperture A, the light is refracted in lengthwise direction. X shows lateral pixel position of the image. Y shows lengthwise pixel position of the image.

We perform correction to the data that we observed in aperture B and C. The prism is set up by aperture C. We revise in the L direction affected by the refraction by the prism. The change of X_3 is influenced by a prism, so we perform correction to the change of X_3. X_{3cor} that is X_3 after having revised is written as;

$$X_{3cor} = \overline{X_3} + \frac{W_N/H_N}{W_P/H_P}(X_3 - \overline{X_3}) \tag{2}$$

where $\overline{X_3}$ shows the mean value of X_3 in all images. So difference of the relative position of the images of aperture B and C l is written as;

$$l_X = X_{3cor} - X_2 \tag{3.1}$$
$$l_Y = Y_3 - Y_2 \tag{3.2}$$

In addition X expresses the coordinate of the longitudinal direction、 and Y expresses the coordinate of the transverse direction. Consequently, variance of the difference of the relative position of two images σ is written as;

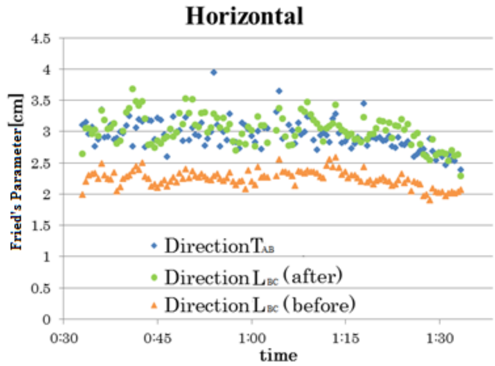
$$\sigma_L = \frac{1}{N}\sum_{i=1}^{N}(l_{Xi} - \overline{l_X}) \tag{4.1}$$
$$\sigma_T = \frac{1}{N}\sum_{i=1}^{N}(l_{Yi} - \overline{l_Y}) \tag{4.2}$$

where i shows the image number, N shows the number of all images, $\overline{l_X}$ shows the mean value of l_X in all images, $\overline{l_Y}$ shows the mean value of l_Y in all images. And, by using the equation (1.1) and (1.2), we can find Fried's Parameter.

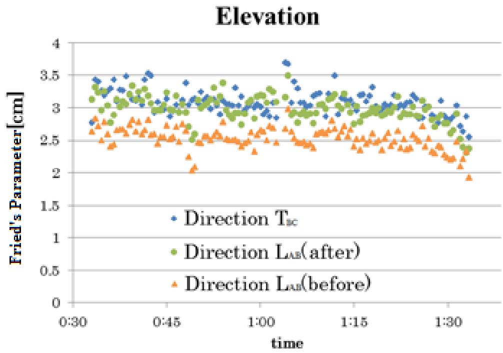
We perform this correction for data of aperture A and B equally. In the case of aperture A and B, the direction refracted by a prism is a lengthwise direction. The prism is set up by aperture A, so we perform correction to the change of Y_1.

C. **Result**

We show the comparison of results before and after correction.



(a) change of Fried's Parameter of the horizontal direction



(b) change of Fried's Parameter of the horizontal direction

Figure 6. Comparison of result before and after correction. "after" means data after the correction and "before" means data before the correction.

Table 5. Average of Fried's Parameter of each direction

	Direction T_{AB}	Direction L_{BC} (after)	Direction L_{BC} (before)
Horizontal	2.935cm	3.014cm	2.242cm

	Direction T_{BC}	Direction L_{AB} (after)	Direction L_{AB} (before)
Elevation	3.086cm	2.975cm	2.522cm

As shown Figure 6 and Table 5, by trying correction, as for the Fried's Parameter of the horizontal direction, each calculated value became nearly the same and we found that we could reduce the effect of the prism. And, as a result of having tried similar revision to elevation direction, we can also reduce the effect of the prism.

Therefore, even if we used the mask with two apertures, we able to measure a value of appropriate Fried's Parameter by adopting this correction.

IV. CONCLUSION

We are able to make DIMM using the small telescope of diameter 10cm. For a problem that a star image enlarged by a prism, we try revision. As a result, we could reduce effect of that. We can measure an appropriate value of Fried's Parameter in both directions

In future, it is necessary to study a cause of this expanse and perform theoretical inspection.

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