The experiment to detect equivalent optical path difference in independent double aperture interference light path based on step scanning method

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ABSTRACT

Fringe test is the method which can detect the relative optical path difference in optical synthetic aperture telescope array. To get to the interference fringes, the two beams of light in the meeting point must be within the coherence length. Step scanning method is within its coherence length, selecting a specific step, changing one-way's optical path of both by changing position of micro displacement actuator. At the same time, every fringe pattern can be recorded. The process of fringe patterns is from appearing to clear to disappearing. Firstly, a particular pixel is selected. Then, we keep tract of the intensity of every picture in the same position. From the intensity change, the best position of relative optical path difference can be made sure. The best position of relative optical path difference is also the position of the clearest fringe. The wavelength of the infrared source is 1290nm and the bandwidth is 63.6nm. In this experiment, the coherence length of infrared source is detected by cube reflection experiment. The coherence length is 30μm by data collection and data processing, and that result of 30μm is less different from the 26μm of theoretical calculated. In order to further test the relative optical path of optical synthetic aperture using step scanning method, the infrared source is placed into optical route of optical synthesis aperture telescope double aperture. The precision position of actuator can be obtained when the fringe is the clearest. By the experiment, we found that the actuating step affects the degree of precision of equivalent optical path. The smaller step size, the more accurate position. But the smaller the step length, means that more steps within the coherence length measurement and the longer time.

Keywords: step scanning method, optical path difference, interference, coherence length, fringe

1. INTRODUCTION

Since 1868, when the French astronomer Fizeau proposed the idea of measuring angle of the diameter of the celestial bodies based on the method of optical interference, the astronomical optical interference technique has an played an important role in synthetic aperture telescope to detect beam parallelism [1], optical path compensation, stripes detection and improve the resolution of the Optical Synthetic Aperture Telescope (OSAT). OSAT is small size telescope array instead of a single large diameter telescope, which can effectively solve some problems such as the insufficient of light gathering, the small angular resolution and the high production cost using the individual large telescope. The development of OSAT will lay the foundation for the Next Generation Space Telescope (NGST). The precondition for producing interference fringes as a whole with some optical synthetic aperture telescopes is between the two coherent telescopes. Two sub aperture telescope interference technology is the foundation of optical synthetic aperture telescope imaging technology, and optical path difference (OPD) is the key factor for OSAT. When two beams meet, only the center frequency component is coherently enhanced on the condition of bigger OPD and other frequency is in a mess, degraded to nearly incoherent state. With the decrease of the OPD, more frequency component is coherently enhanced [2]. Therefore, whether the OPD is controlled accurately has a lot to do with the imaging quality of OSAT. The current method for getting the zero OPD are symmetry criterion method [3], five footwork method [4], Fourier transform method, etc.

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2. ANALYSIS OF PRINCIPLE

2.1 Principle of double aperture interference

By collecting optical interference fringe to get the data, is a means of optical measurement. The ideal monochromatic light interference is the superposition of intensity on the surface of image plane through the two sub-apertures. Its expression is:

$$I(p) = I_1(p) + I_2(p) + 2\sqrt{I_1(p)I_2(p)}\cos\varphi \tag{1}$$

Where $I_1(p)$ and $I_2(p)$ is the intensity of the point p on the image plane which is after each sub aperture telescope. And $I(p)$ is the intensity on the point p that is after superposition of two beams of light. φ is stripe phase, which is the main factor of making stripe changed. With the change of phase, some different quality stripes can be observed. In order to better measure the quality of the interference fringes, another evaluation parameter contrast is introduced. The calculation formula is:

$$K = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \tag{2}$$

Two beams of light interference occurs, not only the conditions of same light frequency, vibration in the same direction and the constant phase difference, but also OPD not exceed the light wave length that is coherence length. The coherence length is calculated by:

$$\Delta L = \frac{\lambda_0^2}{\Delta\lambda} \tag{3}$$

Where λ_0 is central wavelength, $\Delta\lambda$ is bandwidth.

2.2 Description of data collection and processing

Step scanning method is, within the coherence length, one-way optical path changed with the micro displacement actuator, resulting in OPD, making stripe's brightness changed. Select the appropriate actuation step, each frame fringe is recorded by CCD with the change of actuator.

After data collection, select a pixel location where is the maximum gray scale value in one of the fringe pattern. The intensity at the same location in all fringe pattern are recorded as intensity curve. Contrast curve is also used to identify the position of minimum OPD where the actuator is corresponding to. Not only the maximum gray scale value of every frame image is recorded as I_{max}, but also the minimum gray scale value need to be recorded as I_{min}. According to the equation (2), the contrast value can be calculated.

3. DETECTION OF COHERENCE LENGTH BY CUBE EXPERIMENT

The beam path diagram of testing coherence length using cube is shown in Figure 1. The infrared light from optical fiber is changed into parallel light by the 10× beam expander. Then the beam is divided into two ways by beam splitter. One-way beam is incident on the two cube reflector mirrors which are coated with a reflective film. Two beams of light comes together on the front of two circular apertures. Because the spot is divided into two semicircular spots by the cube mirror, the two circular apertures must be covered completely by the two semicircular spots. After the focus lens, the overlapping spots at the focus can be observed with the infrared CCD. Now if the OPD is less than coherence length, the strips can be seen. If there is no stripes, OPD must be reduced by fine-tuning the micro displacement actuator under the one of both cube mirrors. With the decreasing of OPD, infrared stripes appear. If we continue to adjust the actuator in the same direction, the stripes will gradually blurred even disappear (see Figure 2).

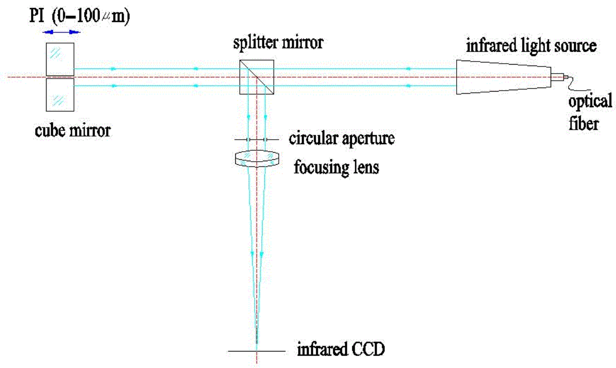

Figure 1. The beam path diagram of testing coherence length using cube mirror

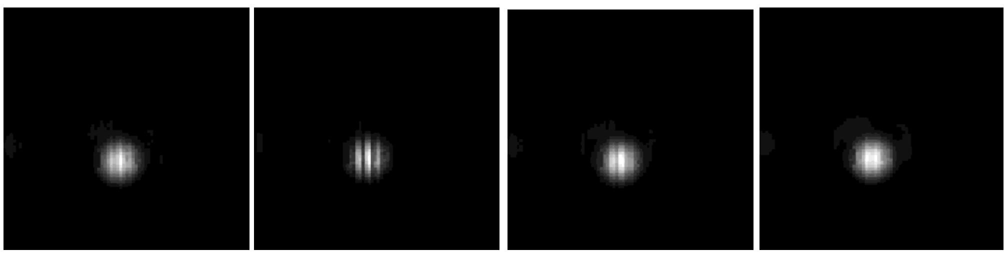

Figure 2. Infrared interference fringe

The above process is to get a rough approximate position of minimum OPD. In order to obtain a more precise position of minimum OPD, the step scanning method is selected. First, the step scanning range and the step size is selected. The table 1 shows the parameters of cubic experiment for testing coherence length. Next, the stripe for each step of the actuator is recorded by CCD. The last step is data processing according to the method in section 2.2. The intensity curve is shown in Figure 3.

Table 1. The parameters of cubic experiment for testing coherence length

Central wavelength (nm)	**Bandwidth (nm)**	**Step size (μm)**	**Range (μm)**	**Numbers**	**CCD Pixel size (μm)**
1290	63.6	0.05	30-70	800	30

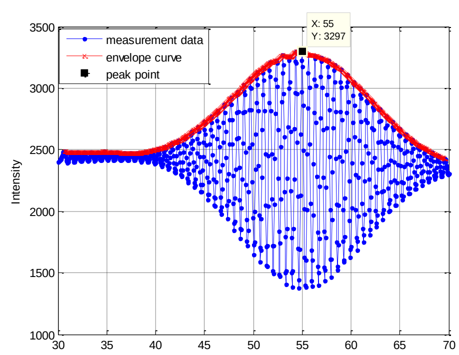

Figure 3. The intensity curve of cubic experiment

As shown in Figure 3, the blue dot represents the measured data of intensity and the red dot represents the envelope curve. From the envelope curve, a peak point (3297) can be found, where the position of actuator is 55 μm that can be approximated recognized as the position of the zero optical path. The contrast curve also can be used to find the approximated zero optical path. The same as Figure 3, the blue dot is contrast value calculated from the measured data and the red dot is envelope curve in Figure 4. The peak point (0.6663) of contrast data in envelope curve and the position (55.24 μm) of actuator can be found. So the approximate position of zero OPD is found.

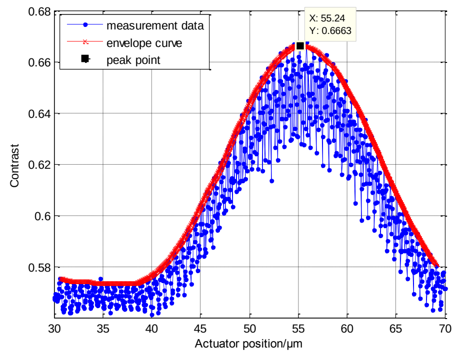

Figure 4. The contrast curve of cubic experiment

According to Figure 3 or Figure 4, fringe is from appear, clear to disappear when the actuation position is form 40 μm to 70 μm. So the measurement coherence length can be thought as 30 μm by subtracting 40 μm from 70 μm. According to the table 1, take the central wavelength and bandwidth into the Eq. (3) to get the theoretical value of coherence length as 26 μm.

4. DOUBLE APERTURE INTERFERENCE EXPERIMENT

The experimental setup of double aperture interference is shown in Figure 5. The light from fiber is focused on the point matched with collimator. The parallel light from collimator passes through two sub aperture telescopes. The light incident on the two 45 ° tilting mirror from the sub aperture telescopes is reflected into two right-angle prism. Then the incident light reflected by two mirrors passes through a focusing lens and finally images on the infrared CCD.

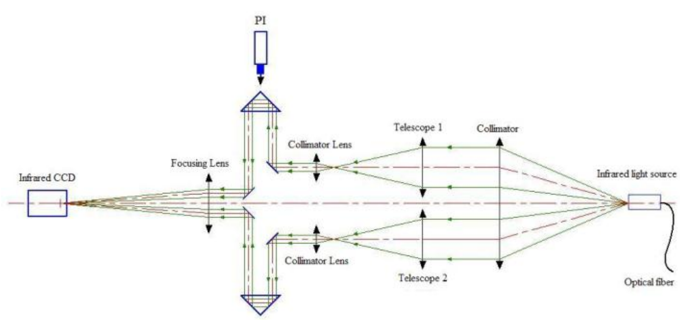

Figure 5. The beam path of double aperture interference experiment

By placing one micro displacement actuator under one right-angle prism of both, make the right-angle prism to move in the same direction so that change the OPD and obtain some pictures with different OPD. Some parameters are same with ones in Table 1, such as central wavelength, bandwidth and step size. The difference is range which is from 890μm to 940μm and 1000 pictures can be obtained. After data processing, the intensity curve and contrast curve is shown on the left of Figure 6 and Figure 7.

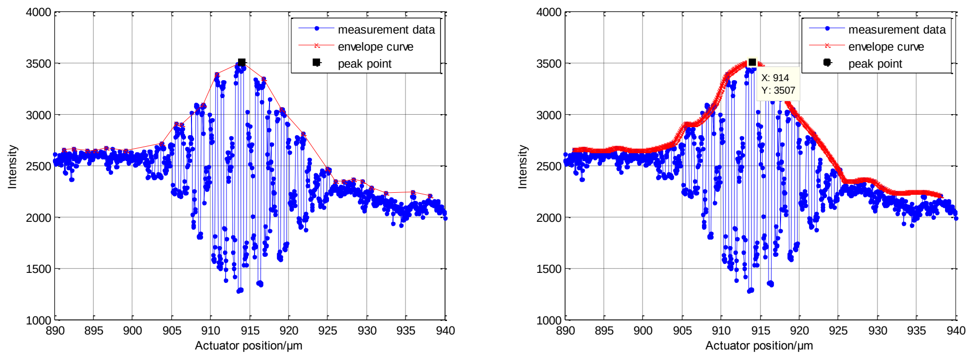

Figure 6. Intensity curve for double aperture interference experiment

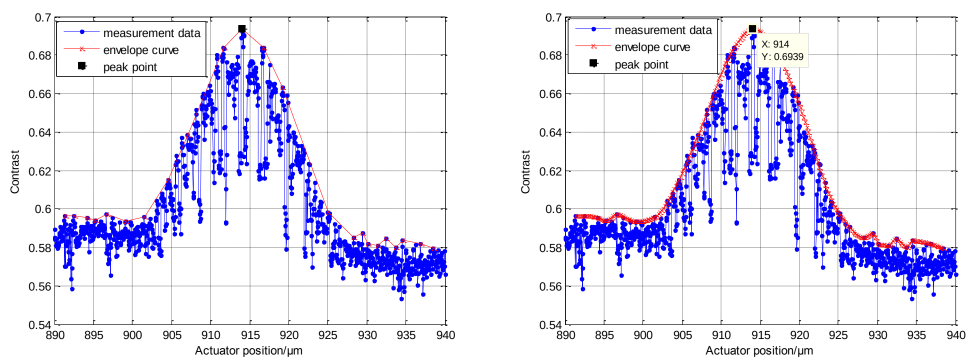

Figure 7. Contrast curve for double aperture interference experiment

As shows in figure 6 and figure 7, due to the complexity of the double aperture interference experiment, the disturb of stray light or background light under the testing conditions, the positioning precision of measurement and the numbers of sampling points, the obtained data have some errors so that the maximum data of intensity and contrast is not matched with minimum OPD. The envelope curve in figure 6 and figure 7 on the left is the envelope of the peaks. Because of the limit of the number of the peaks, the envelope curve is not smooth. To get more accurate position, the envelope curve on the right shows the smooth curve after calculation of interpolation. The square point in figure 6 and figure 7 is peak point corresponding to the actuator position is 914μm from both of intensity curve and contrast curve.

Comparing with the results of cubic experiment, interpolation calculation is a useful method to remove the error caused by the noise. The more precision position of zero OPD can be obtained by calculation of interpolation.

5. CONCLUSIONS

The position of zero OPD for double aperture interference can be precisely determined by step scanning method. The method has the limit of positioning speed because of full range scanning within the coherence length. In addition, the appropriate step size need to be selected for this method. Within the same scanning range, if the step size is bigger, the time it used is shorter, but the positioning precision is low. If the step size is smaller, the positioning precision is improved, but it takes long time. Take both of the speed and the precision into account, the method can be adopted as follows in the future. The bigger step size is chosen within the large scanning range to get the rough peak position of zero OPD. And then centered on the rough peak position, the smaller step size is selected within the small range to improve precision.

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