Development of measurement system for gauge block interferometer

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Abstract. We developed a measurement system for collecting and analyzing the fringe pattern images from a gauge block interferometer. The system was based on Raspberry Pi which is an open source system with python programming and opencv image manipulation library. The images were recorded by the Raspberry Pi camera with five-megapixel capacity. The noise of images was suppressed for the best result in analyses. The low noise images were processed to find the edge of fringe patterns using the contour technique for the phase shift analyses. We tested our system with the phase shift patterns between a gauge block and a reference plate. The phase shift patterns were measured by a Twyman-Green type of interferometer using the He-Ne laser with the temperature controlled at 20.0 °C. The results of the measurement will be presented and discussed.

1. Introduction

Industries use gauge blocks as a standard material measure in the calibration of length measuring instruments [1], such as vernier calipers and micrometer. The gauge blocks need to be calibrated for the requirement of traceability. The ISO 3650:1998 defines the length of a gauge block by the distance at the center of two measuring faces .

Calibration methods can be classified into two types [2]. The first one is the mechanical methods that use a mechanical probe to touch the surface of a gauge block under calibration and a standard gauge block [3]. These methods need to contact the surfaces of the gauge blocks that may influence the dimensions of the gauge blocks. Another type of methods is to utilize interferometers that are non-contact measurement methods.

The interferometer method is a technique that uses light to make an interference pattern. This method is based on the brightness and darkness from constructive and destructive interferences. With the brightness, the fringe patterns can be used to measured the dimension of the gauge block. To measure the gauge block, we have to know the wavelength of the light source that have to be temperature controlled [4]. We count the fringe shift when move some optical devices in the interferometer system or measure the phase shift between the measuring faces of a gauge block under calibration and a reference plate.

In this study, we developed a measurement system for the phase shift analysis by an image processing technique based on open sources such as Raspberry Pi [5], python programming and opencv image manipulation library.

2. Experiment

In order to test the image manipulation and analysis system of the length measurement, we set up a Twyman-Green interferometer [6-7] for creating a fringe pattern. The light source of the system was a stabilized He-Ne laser of Spectra-Physics model 117A which has the wavelength of 632.990 91 nm and the beam size was expanded from the initial size to cover the area of a gauge block.

We employed two convex lenses and a pinhole for expanding the laser beam. Firstly, the beam 0.5 mm was focused by a short focal length 0.65 mm Newport objective lens to the pin hole 50 micrometer that place at the focal point of the lens. Because of the pinhole, the stray light was eliminated. Then the beam was expanded by a second collimating lens Newport 250 mm and 50.8 mm diameter that places behind the pin hole at the focal length of the lens. Thus, the beam was expanded to 192 mm and collimated but with the size of second lens, the actual beam size not bigger than 50.8 mm which this size is big enough for cover the reference flat mirror. The beam was divided into two paths by a 50/50 beam splitter. The first beam came to the Newport 50.8 mm ½ wave reference flat mirror and the second beam came to the gauge block 10 mm nominal that place on a second reference flat mirror. We align the path by measure the central of beam from the optical table with the same high and same position on the beam path that perpendicular the optical table and measure the beam size equality. The two beams were reflected back to the beam splitter and interfered yielding a fringe pattern. A Raspberry Pi 3 Embedded Linux and Raspberry Pi Camera five-megapixel Rev 2.0 as shown in figure 1a and 1b were placed at the opposite of the gauge block to capture the fringe image for the image manipulation and analysis system. The diagram of the set up can be shown as in the figure 2.

Figure 1a. The Raspberry Pi board for image processing and control camera

Figure 1b. Raspberry Pi camera for get fringe pattern from system

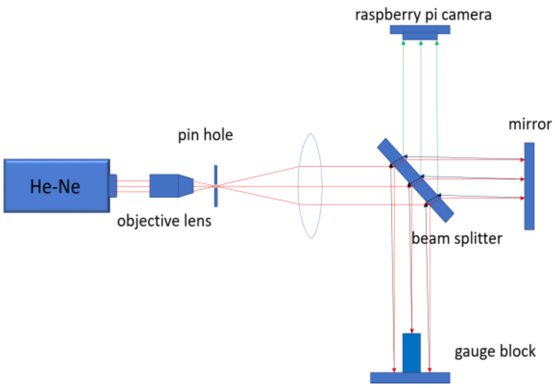

Figure 2. The diagram of optical system and image capturing

3. Results and discussion

To analyze the phase shift or the fringe pattern [8-9], the image obtained from the system was defined the fringe pattern region for analyzed both on the gauge block surface and the reference flat mirror. The image was transformed to gray scale and was calculated the threshold for extract the only fringe image area but with the normal thresholding, the level for extract the fringe image (foreground) from the background is only human selected level. Sometime this level can’t extract the fringe image out perfectly. With our work, we use the special threshold that called OTSU. This threshold method has the ability to extract the fringe from the background by the iteration the threshold value from the minimum 0 to maximum 255 in gray scale image level. This method calculates the weight, mean and variance from 0 to 255 threshold level both foreground and background. Then calculate the sum variance with weight between class foreground and background until find the best threshold level that the sum variance be minimum. At this threshold value is the best for OTSU thresholding method for extract fringe foreground from the unwanted image background [10] and give the result to binary image. The figure 3a, the original image shows the fringe that parallel together on the reference flat mirror. This parallel is surely result from laser beam alignment but the fringe on the surface gauge block not parallel to the fringe on reference flat mirror because the unparalleled of gauge block surface and flat mirror in process of wring. The figure 3b shows the result in binary image of the fringe patterns on the surface of the gauge block. The image sometime has some small holes inside and unsmooth at the edge. To solve this problem, the morphological operation that called closing can smooth the contour edge and fill the holes gap [11-12]. The figure 3c shows the result of morphology with closing operation and the image ready for finding the contours and fringe analysis.

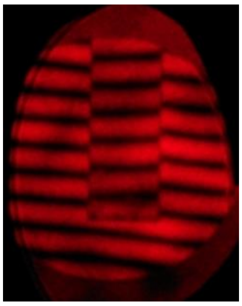

Figure 3a. The fringe pattern on the surface of gauge block and reference flat

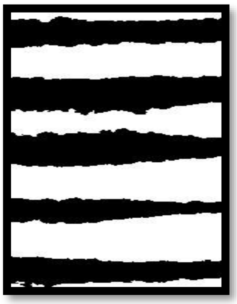

Figure 3b. Image of OTSU thresholding on gauge block

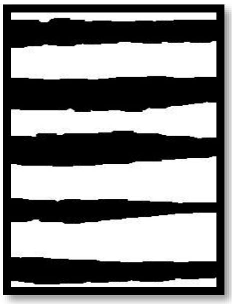

Figure 3c. Output from the morphological closing

From the image that performed the morphological closing has the edge that can be find the contour of the fringes. With each contour on the image, we can estimate the centroid of the contour by calculating the image moment. The moment provides the position of centers on the contour. We used these values to find the fringe fraction or phase shift. Before calculating the phase shift, the image was selected another position outside the gauge block surface but near the first selected position. In the figure 4, the result of the second regions image was shown. The positions of each centroid in the contours mark by the small circles as show in this figure. The distance of centroid between two adjacent contours is associated with the wavelength of the interferometer light source. The phase of the fringes on the gauge block surface may shift from the fringe pattern outside the gauge block. To measure the phase shift, we compare the fringe between the outside and inside the gauge block. If it did not have the phase shift, the both fringe patterns should on the same lines. If it patterns were not on the same line, the phase shift occurred between its and the distance could indicate the phase shift.

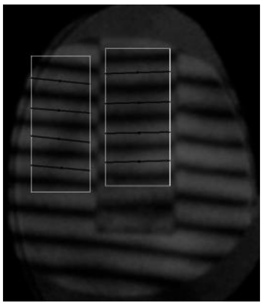

Figure 4. The selected regions on the gauge block surface and on reference flat mirror for phase shift

The image obtained from the measurement had many fringes but in order to measure the phase shift, we selected the region that contains the four obvious fringes. From these fringes, we got the average in the distance between two adjacent equal to 70 pixels and then we calculate the distance shift between the fringes on reference flat mirror and surface of gauge block. With the ISO 3650:1998, the standard uses the middle of the gauge block surface as point of measurement so we use the middle point of the fringe on gauge block as measuring point phase shift. We evaluate phase shift by take the line as the fringe on reference mirror and measure the distance from central point of the fringe on the gauge block to that line and then, we got the average distance equal 34 pixels. The distance 70 pixels is equal to one wavelength so the 34 pixels equal to 34/70 of wavelength. The calculation phase shift result is 307.4527 nm. The measurement result got from the room temperature 20.0±0.5 °C with humidity 40±2% at 1002 mbar. These parameters cause the uncertainty in measuring gauge block length but in my study, we interested in measuring the phase shift that main error from the wavelength and pixel reading. The wavelength calibration by the laboratory at National Institute of Metrology (Thailand) and we got the stability 0.00165 nm and standard deviation 0.00013 nm. The reading pixel distance between two adjacent fringes got the standard deviation equal to 2.3 pixel which cause the error 20.79827 nm. The phase shift got the standard deviation 2 pixel and the associated error is 18.08545 nm. When combine all error the both pixel read error will cause dominance uncertainty.

4. Conclusion

The system that we have developed can measure the phase shift on the reference flat mirror and the gauge block by analyzing the image of fringe pattern. The image was processed with the python opencv library that provides the image manipulate functions. This library was an open source licence and power full for the phase shift measurement by the gauge block interferometer. With this opensource, we can develop the gauge block calibration system with the low cost compare to the commercial system because the Raspberry Pi board and support camera are low in price and the software with no licence cost.

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