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 measure the dimension of the gauge block. To measure the gauge block, we have to know the wavelength of the light source that has to be temperature controlled [4]. We count the fringe shift when moving 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 size of 0.5 mm was focused by a short focal length of 0.65 mm objective lens to the pinhole of 50 μm that placed 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 of 250 mm and 50.8 mm of diameters that placed behind the pinhole at the focal length of the lens. Thus, the beam was expanded to 192 mm and collimated but with the size of the second lens. The actual beam size was not bigger than 50.8 mm which was big enough for covering the reference flat mirror. The beam was divided into two paths by a 50/50 beam splitter. The first beam came to the 50.8 mm of a ½ wave reference flat mirror and the second beam came to the gauge block of 10 mm that place on a second reference flat mirror. We aligned the path by measuring the center of the beam from the optical table with the same height and same position on the beam path that was perpendicular to the optical table and the same beam size. The two beams were reflected back to the beamsplitter and interfered yielding a fringe pattern. A Raspberry Pi 3 Embedded Linux and Raspberry Pi Camera five-megapixel Rev 2.0 as shown in figures 1a and 1b were placed at the opposite side 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 figure 2.

![Figure 1a. The Raspberry Pi board for image processing and control camera](image1)

![Figure 1b. Raspberry Pi camera for get fringe pattern from system](image2)

**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 grayscale 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. Sometimes this level cannot extract the fringe image perfectly. With our work, we used 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 grayscale image level. This method calculates the weight, mean and
variance from 0 to 255 threshold level both foreground and background. Then, we calculated the sum variance with the weight between class foreground and background until finding the best threshold level that the sum variance was minimized. 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 a binary image. The figure 3a, the original image shows the fringe that parallels together on the reference flat mirror. This parallel resulted from laser beam alignment but the fringe on the surface gauge block was not parallel to the fringe on reference flat mirror because the unparalleled of gauge block surface and the flat mirror were in process of wringing. The figure 3b shows the result in the binary image of the fringe patterns on the surface of the gauge block. The image sometimes 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 the 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](image1)

![Figure 3b. Image of OTSU thresholding on gauge block](image2)

![Figure 3c. Output from the morphological closing](image3)

From the image that performed the morphological closing has the edge that can 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 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 shown 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](image4)
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 calculated 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 the point of measurement so we used the middle point of the fringe on gauge block as measuring point phase shift. We evaluated phase shift by taking the line as the fringe on the reference mirror and measured the distance from the central point of the fringe on the gauge block to the line. Then, we got the average distance equal to 34 pixels. The distance of 70 pixels is equal to one wavelength so the 34 pixels equal to 34/70 of wavelength. The calculated phase shift result was 307.4527 nm. The measurement results obtained from the room temperature at 20.0±0.5 °C with 40±2% of humidity. These parameters could influence the uncertainty in the measured gauge block length. However, we interested in the uncertainty that contributed by the wavelength and pixel reading. The wavelength calibration was carried out by the laboratory at National Institute of Metrology (Thailand) and we got the stability of 0.00165 nm with 0.00013 nm of the standard deviation. The reading pixel distance between two adjacent fringes provided the standard deviation of 2.3 pixels which caused 20.79827 nm of the standard uncertainty. The phase shift provided 2 pixels of standard deviation that corresponded to 18.08545 nm of the standard uncertainty. When combining all of the uncertainty sources, the pixel reading related uncertainty sources were dominated.

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 the fringe pattern. The image was processed with the python opencv library that provides the image manipulate functions. This library was an open source license and powerful for the phase shift measurement by the gauge block interferometer. With this open source, we could develop a low-cost gauge block calibration system.

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