# The Comparisson between LBP and SQI Methods in the Surface Roughness Measurement Using ESPI Method

Mohammad Khoirul Effendi[1], Agus Sigit Pramono[1], Pandu Pratama[1], and Rifki Wardana[1]

*Abstract*— **Surface roughness measurement using direct contact methods raises several issues, for examples stylus wear and size limitation problems. Furthermore non-contact methods are proposed to solve these problems. One of them is Electronic Speckle Pattern Interferometry (ESPI), which use Helium-Neon (He - Ne) as laser light source. A speckle pattern is produced by scattered light on the surface of the measuring object due to the interference of laser beams, and it will be captured by Charge Coupled Device (CCD) camera. Afterwards Linear Binary Pattern (LBP) and Self Quotient Image (SQI) methods are used to reduce illumination effect in the captured image. The average gray-level from the previous process will be converted into a surface roughness value by gray level to surface roughness conversion formulation. It is obtained from correlation value between gray level and a set of standard roughness. The standard roughness value range is start from 0,05 µm to 12,5 µm. It is measured from five different final machining process, which are flat lapping, grinding, horizontal milling, and vertical milling. As verification, the results of ESPI method will be compared with the result of direct contact tools using Mitutoyo Surftest 301 and 401**

*Keywords*—**Surface Roughness, ESPI, LBP, SQI, FAR, FRR**

## I. Introduction

Quality of a product is determined by several indicators, one of them is the value of surface roughness. In the direct contact method, surface roughness is measured by moving a sensor (stylus) on the surface of the measuring object. Measuring time, the limited size of stylus tip and wear are weaknesses that must be considered when using this method.

In the measurement using the direct contact method, the stylus must be driven over the surface slowly to ensure the accuracy. This condition allows surface measuring time in direct contact is longer than indirrect contact method. The limited size of the stylus tip is another factor must be considered. Radhakrishan, 1970 [1] and Mc Cool, 1984 [2] state that the size of the stylus tip has a considerable effect on the accuracy. The accuracy increased by decreasing the size of stylus tip, but in the other side the damage probability will increase too.

Poon and Bhushan, 1995 [3], stating the occurrence of damage on the object surface and stylus tip caused by friction each other which is referred as micro-scratches. The occurrence of micro-scrathes in surface roughness measurement lead to inaccurate measurement. In this condition the stylus tip does not measure the roughness value, but also scratch the surface of the measured object.

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As the result, the roughness value will be different in the repeated measurement. Non contact method are method which are developed to solve problem in surface measurement using contact methods. Laser is common light that used as a tool to measure the surface roughness of an object, which is known as Electronic Speckle Pattern Interferometry (ESPI).

In the previous study, Rakiman 2007 [4], stated that the influence of illumination is neglected, so that the sampling area for measurement should be selected manually. Furthermore the measurement of the surface roughness can not be done automatically. In this study, the method of Linear Binary Pattern (LBP) and the Self Quotient Image (SQI) will be used as illuminate compensation to increase the accuracy of measurement by compensate the dark side of surface image in order to make measurement runs automatically.

## II. Methods

In the ESPI method, a laser beam is used to display an image of surface roughness of an object which isthe standard of surface roughness comparator in industry. Afterwards the images are processed through several stages of image processing to produce the gray level values. Finally a converting equation from gray level to the actual surface roughness will be produced.

As verification, the results of surface roughness measurements using ESPI method will be compared with the results of direct contact measurement method (Mitutoyo Surftest 306 and 401) to determine the accuracy level of this method. In addition the value of FAR (False Accepted Ratio) and FRR (False Rejected

Ratio) will be presented to show the performance of ESPI method through a series of training, validating, and testing processes. The general flowchart of this experiment able to see in the Figure 1.

*A. Electronic Speckle Pattern Interferometry (ESPI)*

Electronic Speckle Pattern Interferometry (ESPI) method or also known as TV Holography was invented around the 1970's. The basic principle of ESPI mechanism has been developed by Macoski [5] in the USA, Schowomma [6] in Austria, and Butters & Leendertz in England [7]. This method is generally used for a various applications such as measurement of surface roughness, stress-strain measurement, vibration analysis, and non-destructive test to evaluate the characteristic of a material.

The working principle of this method can be seen in Figure 2. Laser beam of He-Ne laser produces laser with 0.7 mm in size. Unfortunately the size is too small to be used in the sampling process of surface roughness. Therefore Beam Expander (BE) is used to enlarge the laser beam size until 5 times from the original size. The characteristic of laser beam that come out from the Beam Expander (BE) is unpolarized. Therefore, Beam Splitter (BS) is used to change it into polarized form which is separated to the vertical and horizontal directions. The horizontal polarized laser beam will be directed towards the object of measurement, while the vertical polarized will be directed toward the mirror as a reference. The reflecting beam from the surface of the measured object and from the reference surface will interfere each other to produce new beam with varied amplitude, phase and intensity. Therefore, the new beam will be varied depend on the information of surface roughness of measuring object.

In the next step, the interfere image will be captured by Charge Coupled Device (CCD) camera. If the reflected beam from the reference has the same phase with the reflecting beam of the measured object, then a bright spot will be produced in the CCD camera as captured images. In the opposite, if the phase of interfere beam is not same each other, then the black spot will be appear in the CCD camera.

Set-up modeling of surface roughness gauges with ESPI method in this experiment can be seen in Figure 3. Setting each component measurements on the picture is taken from Twyman-Green laser interferometry model which is designed to test the surface curves. In this experiment, the original set-up of Twyman-Green using Pyroviewer which used for recording, is replaced by CCD Camera. In the other hand the TV monitors in original set-up is replaced by monitor and CPU.

The composition of surface roughness measuring gauges with ESPI method can be described as follows:

*1) Object Measuring Standard (Standard Comparator)*

Comparator used in this study are examples of a workpiece surface roughness resulted from the end of the machining process such as shown in Figure 4. This comparator is made by Rubber & CO. Ltd.. Type 130: Composite Set of Roughness Specimens. The comparator consists of 30 specimens of the workpiece surface, which include six machining methods that frequently used by the industry. They are Lapping (6 samples), Reaming (6 samples), Grinding (6 samples), Horizontal Milling (6 samples), Vertical Milling (6 samples ), and Turning (6 samples). The detail value of surface roughness of each specimen can be seen in the description below;

i. Lapping : With surface roughness values (Ra) (0.005 ; 0.1 ; 0.2 µm).
ii. Reaming : With surface roughness values (Ra) (0.4 ; 0.8 ; 1.6 µm).
iii. Grinding : With surface roughness values (Ra) (0.005 ; 0.1 ; 0.2 ; 0.4 ; 0.8 ; 1.6 µm).
iv. Horizontal Milling : With surface roughness values (Ra) (0.005 ; 0.1 ; 0.2 ; 0.4 ; 0.8 ; 1.6 ; 3,2 ; 6,3 ; 12,5 µm).
v. Vertical Milling : With surface roughness values (Ra) (0.005 ; 0.1 ; 0.2 ; 0.4 ; 0.8 ; 1.6 ; 3,2 ; 6,3 ; 12,5 µm).
vi. Turning : With surface roughness values (Ra) (0.005 ; 0.1 ; 0.2 ; 0.4 ; 0.8 ; 1.6 ; 3,2 ; 6,3 ; 12,5 µm).

*2) He Ne Laser*

Laser used in this experiment is the He Ne laser. He Ne laser is a type of laser that used ordinary neutral gas Helium-Neon as the active medium. This type of laser beam has a good quality so it is suitable for measurement processes that require a high level of accuracy, inexpensive, low power, compact, and does not require cooling system[8]. Physical form of He Ne laser and its power supply can be seen in Figure 5 and Figure 6. Power supply of the laser using 220 AC input voltage. He Ne laser summary characteristics are shown in Table 1.

*3) Beam Splitter*

In this ESPI method, beam splitter is one component that served to divide the laser beam. The unpolarized input of the laser beam will be divided into two polarized light with a flat and vertical directions as shown in Figure 7.

*4) Beam Expander*

Beam expander lens is a lens arrangement that served to enlarge the laser light. Size of the He Ne laser beam is 0.7 mm. The size is still very small when used as a sampling medium in measurement process of surface roughness. Therefore the size of the laser beam should be magnify 5 times using a magnified lens Beam Expander (BE). The magnified lens consists of two convex lenses commonly called Keplerian Galillean composition or arrangement. The lens consist of a concave lens and a convex lens as shown in Figure 8. In this study the composition of the beam expander used is Galilean type.

*5) Flat Table*

To produce an image from surface roughness measurement of an object precisely, it requires a flat table as shown in Figure 9. The average table is used for eliminating errors equipment that arised due to the difference in height between the components. Data collection was performed at the Laboratory of Engineering Physics Fotonika Teknik Mesin ITS.

*6) CCD Camera*

CCD camera is a device that serve to visualize the result of interference between light rays which reflected by the measuring object and a reference beam. The CCD camera which used in our experiment is "CANON" type SX 20.

*7) Central Processing Unit (CPU)*

CPU is a functional unit for storing, processing the interference image, perform the calculation and verification of the gray level surface roughness measurement standard. Data processing using a computer with Dual Core processor 2 GHz, and 4 GHz DDRAM

### *B. Image Processing*

The image processing are steps to convert an image which captured by CCD Camera into surface roughness value in a numerical data . All stages of image processing can be seen in figure 10.

In the beginning, the input image is in Red Green Blue (RGB) format, which is should be changed to be Gray Image to reduce computational load in computational software. The equation (1) is the formulation to perform it, where R, G, and B is the value of Red, Green and Blue in color image. The result of conversion can be seen in Figure 11.

$$gray\ image = (0.2989 \times R) + (0.5870 \times G) + 0.1140 \times B) \quad (1)$$

The purpose of cropping image is to cut unnecessary part in an image. This process includes the stages to convert a gray image into a binary image, median filter, and xy projection. If the unnecessary part is able to remove sucessfully, then the surface roughness data retrieval process can be performed automatically.

The next stage is conversion from Gray Image to Binary Image. This algorithms converts a Gray Image that range from 0 to 255 pixels into a Binary Image with 0 or 1 pixel value based on the equation (2). The example of this process can be seen in Figure 12.

$$If\ Gray\ image(x,y) > 50\ then\ Binary\ Image(x,y) = 1\ else\ Binary\ Image(x,y) = 0 \quad (2)$$

Median filter is a method to eliminate noise of an images without reducing it sharpness. Output image is determined by the value of the median value based on equation (3). The example of this process can be seen in Figure 13.

$$y[m,n] = median\{x[i,j], (i,j) \in w \quad (3)$$

XY projection is an algorithm to determine the boundary (left, right, top, and bottom) of cropping image based on the value of Binary Image. The process to determine the boundary can be seen in Figure 14. In this figure, all of one value will be collected either on the X and Y to get the boundary as mentioned above.

Finally, the cropping image will be performed based on the boundary value from the previous stage, which can be seen in Figure 15.

The results of cropping has a varied size value from each other due to the limitation of camera specification. The function of resizing is to equalize the size of all image to be 256 x 256 pixels in order to make measuring process working automatically.

Linear Binary Pattern (LBP) is one of the techniques used in image processing which used to eliminate the dark side of an image. The condition is caused by the differences of light intensity of an image, and it changes the gray level values of Gray Images. It needs to be removed to keep the original value of surface roughness of a measured object. The applications of LBP are widely used in various studies such as measurement of surface roughness of steel [9] and crack detection [10].

The LBP formulation in the image processing can be seen in equation (4) and (5) [11]

$$LBP(x_c, y_c) = \sum_{n=0}^{7} s(i_n - i_c)2^n \quad (4)$$

Where $i_c$ is the gray level value at the centre $(x_c, y_c)$ and the function $s(x)$ is definied by

$$s(x) = \begin{cases} 1 & if \quad x \geq 0 \\ 0 & if \quad x < 0 \end{cases} \quad (5)$$

The example of this process can be seen in Figure 16

Self Quotient Image is a method to normalize the dark parts of the image due to differences in illumination of the images. An image output using SQI (Q (x, y)) is defined by using the equation (6);

$$\mathrm{Q(x,y)} = \frac{\mathrm{I(x,y)}}{\mathrm{S(x,y)}} = \frac{\mathrm{I(x,y)}}{\mathrm{F(x,y)*I(x,y)}'} \quad (6)$$

Where S (x, y) is an image (I) that has been smoothed. F (x, y) is a smoothing kernel and * is the convolution operation [12]. One example of the results of the SQI image can be seen in Figure 17.

Union Jack sampling method is used to know the gray level of an imageWith this method, each gray level of an image is assessed using the 8 sampling line then eighth grades are averaged. Examples of surface roughness sampling with union jack method can be seen in Figure 19, while the value of gray level sample point 1 and 3 can be seen in Figure 19.

This process is used to increase the number of images that used in the training and testing processes. Each image will be rotated.The rotation is happen every $2^o$, from $0\text{-}180^o$.

Subsequently 120 images are used for the training process and the rest is used for validating process. This process serves to calculate the False Acceptance Ratio (FAR) and False Rejected Ratio (FRR) which value is used to calculate the performance of the ESPI method in surface roughness measurement. Examples of the results of the image rotation process can be seen in Figure 20.

### *C. FAR, FRR and Euclidian Distance*

False Acceptance Ratio (FAR) and False Rejected Ratio (FRR) is a standard value which used as a benchmark for comparing the performance of this method with the other methods. Gray level value of 120 images in the training process averaged, and then the remaining 60 images will be used as an input for the testing process with euclidian distance method. Euclidian distance is a method for calculating the distance between two pieces of objects based on the value of the feature that owned the $2^{nd}$ object, following equation (7)

$$d_{ij} = \sqrt{\sum_{k=1}^{n}(x_{ik} - x_{jk})^2} \quad (7)$$

Where $d_{ij}$ is the euclidian distance value of the element $x_i$ and $x_j$.

In the training process, the value of 120 images taken its average gray level, continued testing phase to find the value of FAR and FRR. Euclidian distance formula used to determine the distance to the nearest 60th of the testing image. Results of FAR and FRR value can be seen in Figure 21 and Figure 22.

The next process is to change the surface roughness values in gray scale to micro-scale level meter (lm). For the conversion process, the value of gray level associated with a standard roughness values through an equation y = f (x). Where the y-axis is the roughness value in units of gray level, and the x-axis is the value of surface roughness standards in micro meter (µm). Both are the value of the line search equation with $R^2$ values approaching 1. Equation which serves to change the surface roughness values in gray scale to micron-scale level using LBP methods can be seen in Equation (8).

$$Ra = \left[\frac{Lg}{129.86}\right]^{1/(0.033)} \quad (8)$$

In the other side for SQI method is formulated as seen in equation (9)

$$Ra = \left[\frac{Lg}{108.77}\right]^{1/(-0.035)} \quad (9)$$

Where:
Ra = surface roughness value in micrometer (µm), and
Lg = surface roughness value in pixel.

Furthermore the value of the surface roughness surftest Mitutoyo 301 and 401 are also searched the line equation with standard roughness values. It serves as a verification of the results of roughness measurements ESPI method with standard measurement tools. Comparison of the results of the surface roughness ESPI method, Mitutoyo surftest 301 and 401 can be seen in figure 23.

In figure 20, it can be seen that the value of the error will be growing with the increasing value of roughness. This is caused by scattering angle of object measurement which it makes interference images can not captured by CCD camera. Beside it, the presence of blur factor on the image makes the gray level values is not correlated with the value of surface roughness in a object surface.

The user interface to measure surface roughness using LBP and SQI method can be seen in the Figure 24. It is created in order to make surface roughness measurement process tools more user friendly to the users.

## III. Results and Discussion

From these results, several conclusions can be drawn as follows;

a. The conversion equation to calculate the value of the surface roughness (Ra) in pixel units into micrometer (µm) unit for LBP method is formulated by;

$$Ra = \left[\frac{Lg}{129.86}\right]^{1/(0.033)}$$

In other side for SQI method is formulated by:

$$Ra = \left[\frac{Lg}{108.77}\right]^{1/(-0.035)}$$

Where:
Ra = surface roughness value in micrometer (µm),
Lg = surface roughness value in pixel.

b. The errors in this method due to angle laser light scattering from random objects and measuring very large, consequently beam interference results not caught on camera CCD. Therefore the possibility of using more than one CCD camera, with a variation of captured angle is highly recommended for optimization of measurement results.

c. Blurr in captured images, which occured due the focussing in lens setting is the other factor which it incereases the error on the measurement results,.

d. With the existence of errors, the LBP method is suitable for the surface roughness measurement smaller than 3.2 microns. In other side SQI method is suitable for value less than 1.6 microns.

e. In this experiment,only one feature (gray level) that is used in the process of training and testing. The other features such as direction of strokes etc. need to be considered to reduce the error of measurement.

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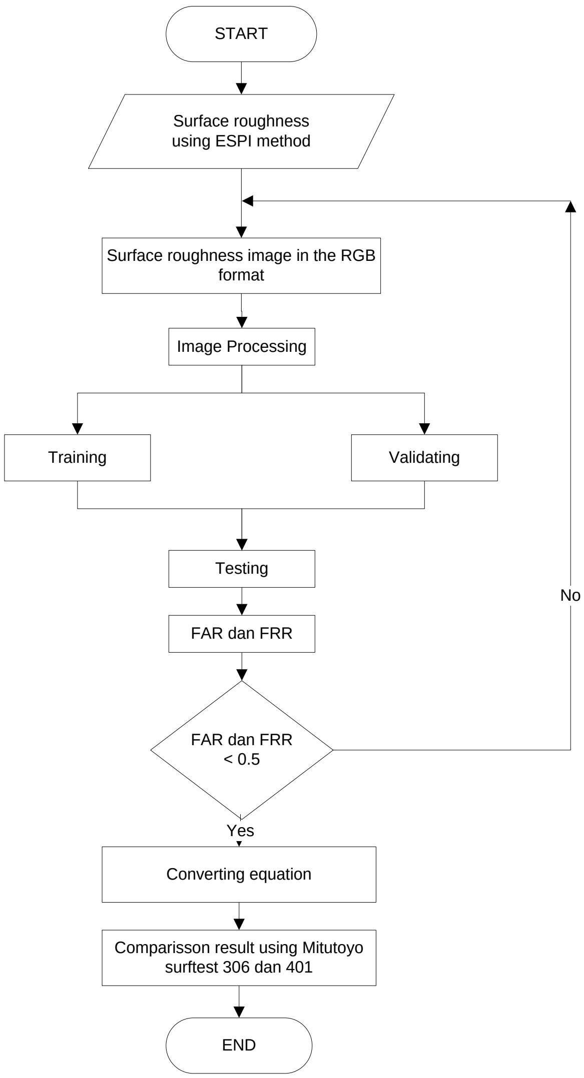


Figure 1. General flowchart of the experiment

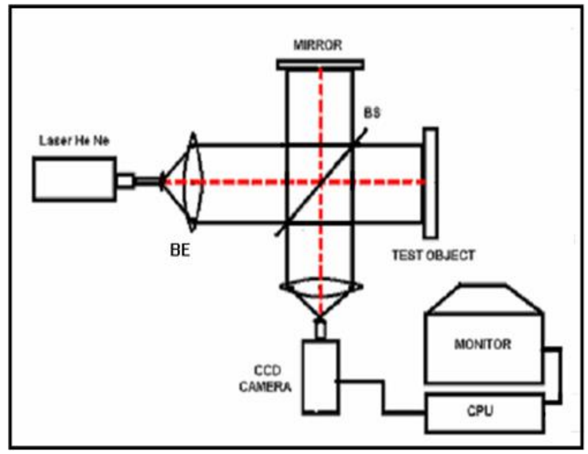


Figure 2. The principles of ESPI method

Figure 3. The tools set-up in ESPI method.

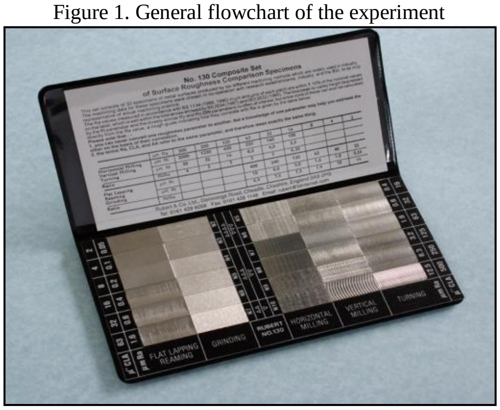

Figure 4. The standard comparator.

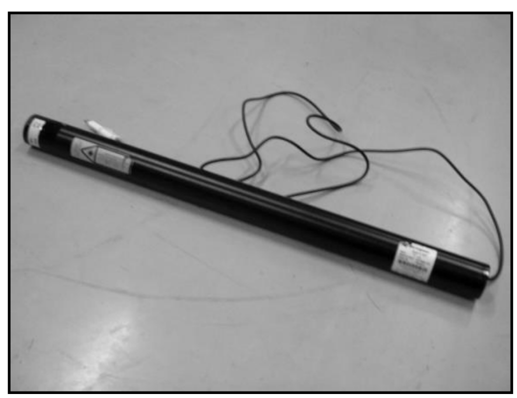

Figure 5. He-Ne Laser


Figure 6. Power Supply of He Ne Laser.

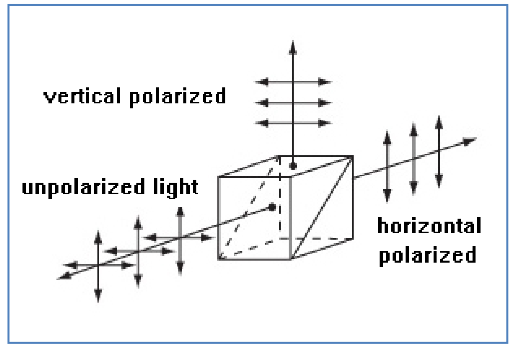


Figure 7. Beam splitter

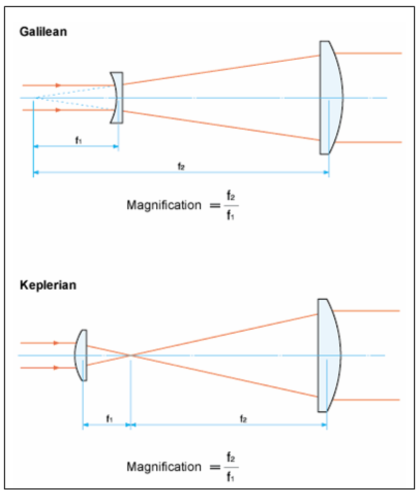


Figure 8. Beam expanders.

Figure 9. The ESPI setup in flat table

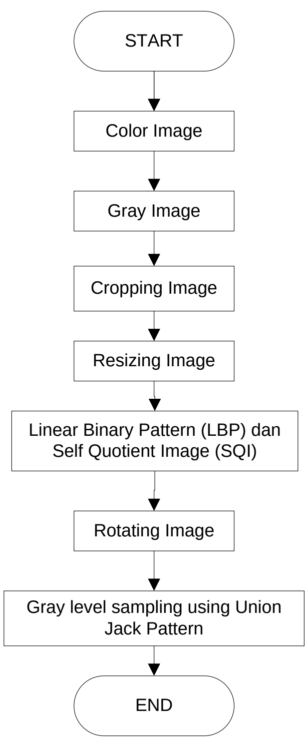


Figure 10. Stages of image processing.

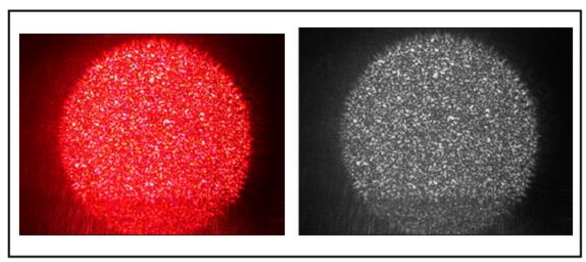

Figure 11. An example of conversion from RGB to Gray Image

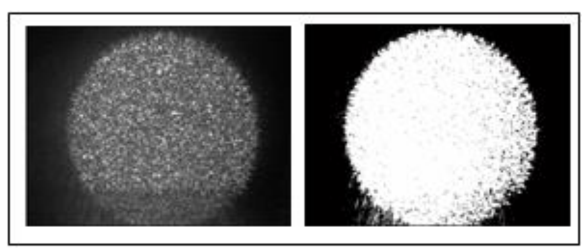

Figure 12. An example of conversion from Gray Image to Binary Image.

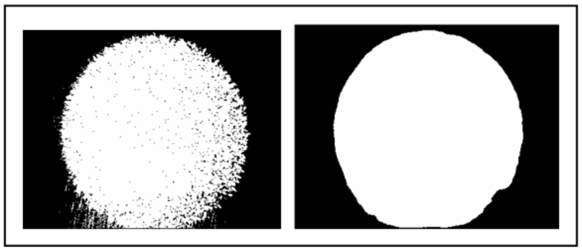

Figure 13. The result of median filter.

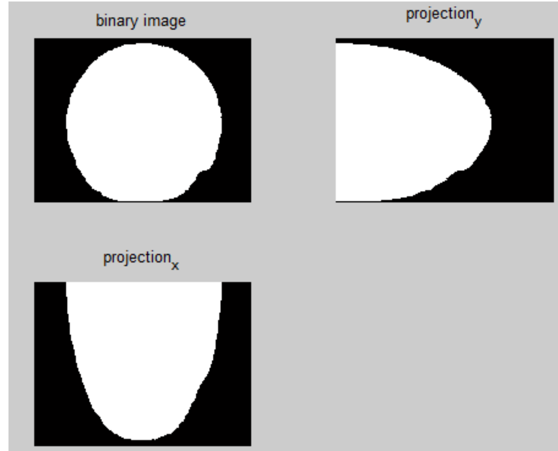


Figure 14. XY projection for a Binary Image.

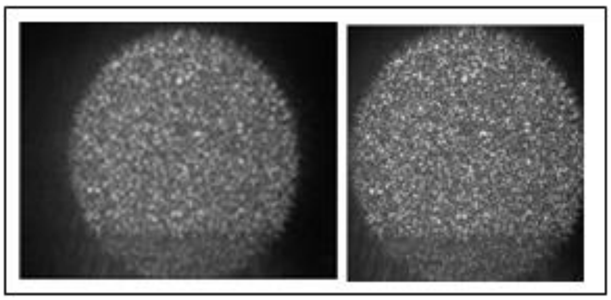

Figure 15. The cropping result.

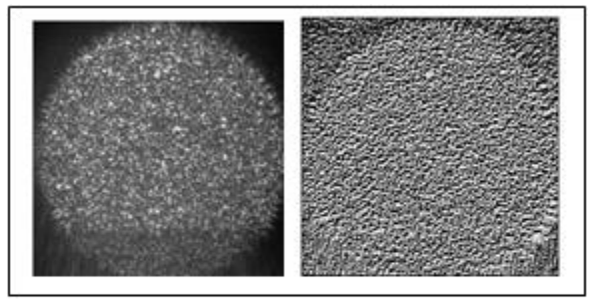

Figure 16. The LBP result.

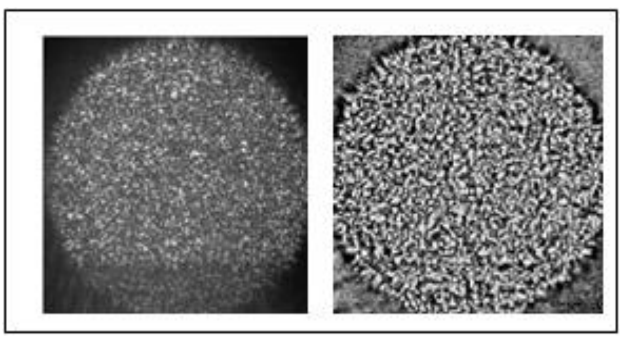

Figure 17. The SQI result.

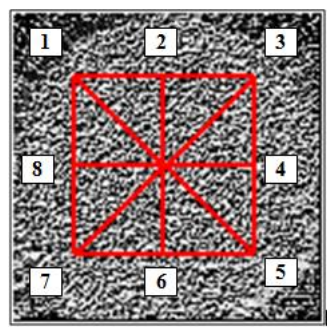


Figure 18. Cropping image using union jack pattern

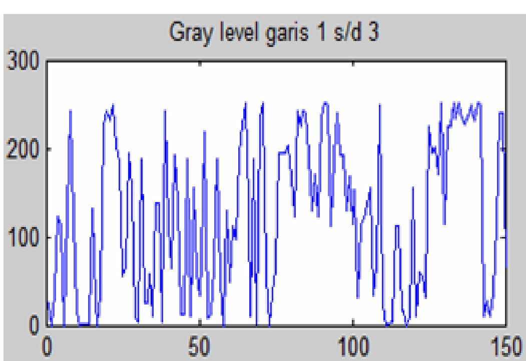


Figure 19. The example of gray level value for point 1 and 3.

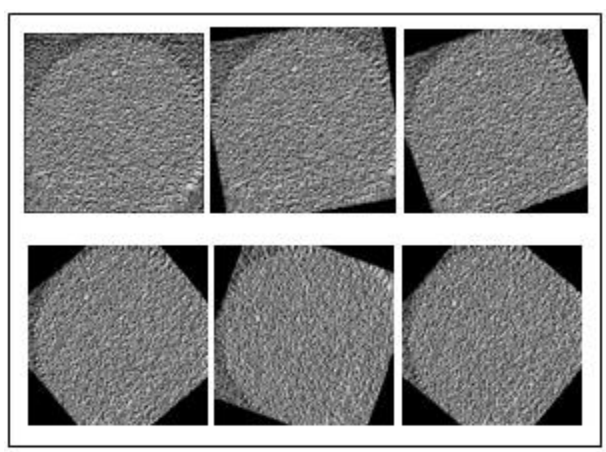

Figure 20. Examples of the results of image rotation process.

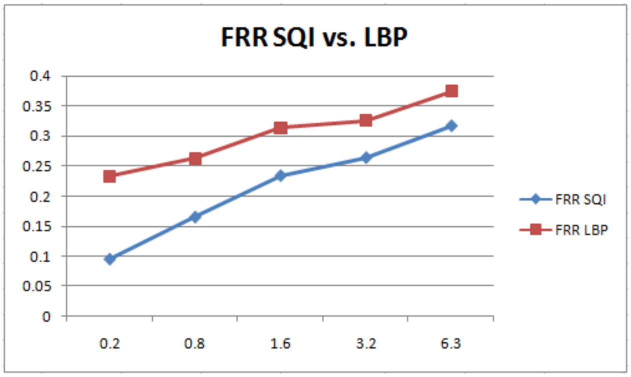


Figure 21. FRR comparisson between SQI and LBP methods

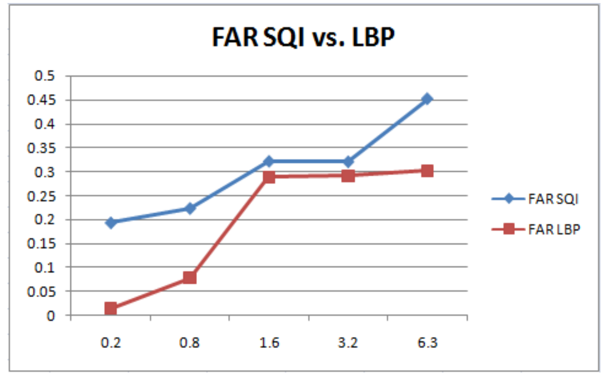


Figure 22. FAR comparisson between SQI and LBP methods

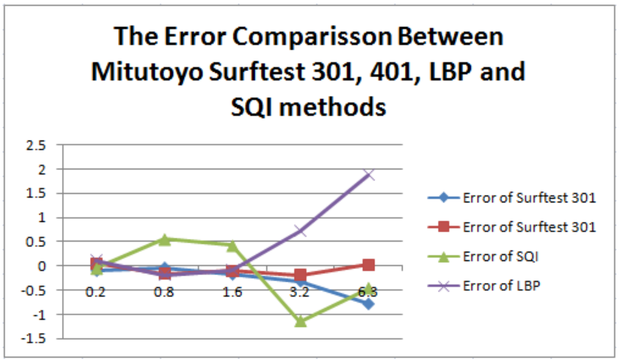


Figure 23. Error comparisson between Mitutoyo Surfte4st 301, 401, SQI and LBP methods

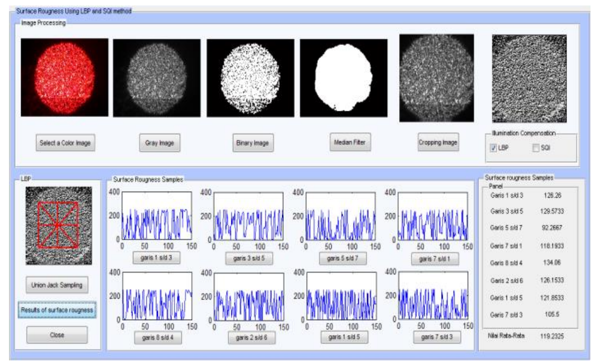

Figure 24. User interface to measure surface roughness using LBP and SQI methods

TABLE 1.
THE SUMMARY OF HE-NE PROPERTIES

| Summary for Helium-Neon Laser | |
|---|---|
| Manufacturer | JDS Uniphase |
| Power supply Model | 1218-2 |
| He-Ne Head Model | 1145 |
| Active Medium | Neon Gas |
| Output Wavelength | 632.8 nm |
| Power Range | 0.1 mw – 100 mw |
| Pulsed on or CW | CW |
| Excitation | Electrical (500-3000-v DC) |
| Polarization | Unpolarization or Linier |