Light Spectrum Speckle Analysis in Roughness Material Identification by Using Naïve Bayes Classifier-Based Equalization Histogram Adaptive

M. Arief Bustomi*,[1] Edwin W. Utama,[1] and Endah Purwanti[2]

[1]*Department of Physics, Insitut Teknologi Sepuluh Nopember (ITS), Surabaya, 60111*
[2]*Department of Physics, Universitas Airlangga (Unair), Surabaya, 60115*

Abstract: Speckle imaging is a method that has been used in various fields. This method can be used to analyze the surface roughness of an object. Speckle imaging uses laser light and observes speckle patterns formed from light interference on the surface. The speckle imaging method is very safe and does not require any contact so it is easy to detect the roughness of an object. In this research, two types of sandpaper were used as rough surface objects. Speckle images of the sandpaper surface were created using three laser diodes with different wavelengths, namely 405 nm, 550 nm, and 650 nm. Image processing in this research begins with pre-processing methods, image segmentation, feature extraction, and then the classification process. The feature extraction process uses an Adaptive Histogram. The classification process uses the Naïve Bayes classifier method. Based on the research results, it was found that variations in the wavelength of the light spectrum affect the results of the Adaptive Histogram image features. The accuracy of Naïve Bayes classification increases if the wavelength used in creating the speckle image is shorter. Identification accuracy increased from 92% to 96% due to the use of speckle images resulting from diode laser irradiation from 650 nm to 405 nm.

Keywords: Histogram, Image Processing, Light Spectrum, Roughness.

*Corresponding author: a_bustomi@physics.its.ac.id

Article history: Received 05 May 2023, Accepted 02 August 2023, Published October 2023.
http://dx.doi.org/10.12962/j24604682.v19i3.18482

I. INTRODUCTION

Technological development has led us to huge movements in the world. One of the technological developments is speckle imaging. Speckles occurred due to light interference which formed a dark and light pattern. This effect occurred when reflected light and incident light formed an interference pattern [1]. This technique has been widely used in many human sectors such as biomedical, industrial, and material identification [2, 3].

This technique is very simple compared to other methods in material identification. This technique is not destructive, no physical contact is required, and only uses light [4]. For example, many methods to analyze roughness analysis. Goode in 2021 used droplets to solve this problem. This is harder if compared with speckle imaging [5]. But, to analyze this image processing is required [6]. This is why speckle imaging is used for roughness material identification [7].

Speckle analysis depends on the material and light spectrum. Postnov et al. 2019 show that contrast in speckles is affected by different light spectra [8]. For this reason, a statistical approach is used to assist this analysis process. This statistical approach is related to feature extraction which is used for roughness material identification [9]. Based on this explanation, image processing is used in this process.

Image processing has many methods such as Grey Level Co-occurrence matrix, Equalization Histogram Adaptive, and others. Image processing consists of three processes which are image processing, RGB to gray conversion, and feature extraction. Equalization Histogram Adaptive is used on this research on this research based on its accuracy and simple method. The classification process uses a Naïve Bayes classifier which is simpler and more accurate [9]. This statement leads this research to use Naïve Bayes as a classifier method.

This research aims to analyze the effect of variations in the wavelength of the light spectrum on the ability to identify surface roughness speckle images of objects. The speckle image identification process uses a Naïve Bayes Classifier based on adaptive histogram features. The news of this research is on the use of variable wavelength light sources to form digital images and their influence on the process of identifying objects in the digital image. The light source in this research is a laser diode which will produce a digital image in the form of a speckle image. The information contained in the speckle image is related to the surface roughness of the object in the form of sandpaper.

II. METHODOLOGY

In this research, the sandpaper roughness identification process was carried out using speckle images. Speckle images are obtained by illuminating the surface of sandpaper using a laser diode. Digital image processing is used to obtain adap-

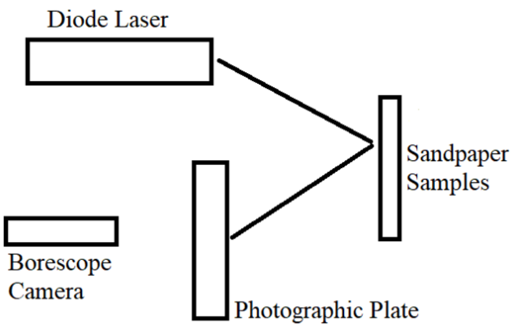


FIG. 1: Experimental setup for recording sandpaper speckle images

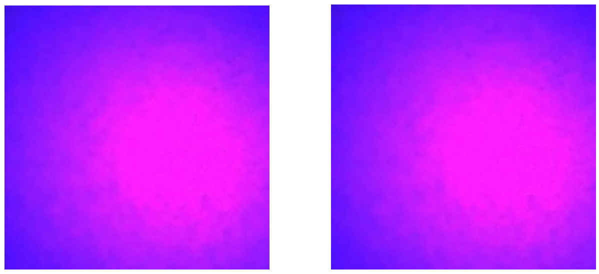


FIG. 2: Image segmentation on first class (a) and second class (b) after irradiated by 405 nm light

tive histogram features from speckle images resulting from laser diode irradiation. This research consists of three main stages, namely the speckle image recording experiment stage, the speckle image processing stage, and the sandpaper roughness identification stage.

A. Speckle Image Recording

Speckle image recording experiments were carried out using three types of laser diodes, namely red spectrum color laser diodes (wavelength 650 nm), green spectrum color laser diodes (wavelength 550 nm), and blue spectrum color laser diodes (wavelength 405 nm). The sandpaper is illuminated with each laser diode to form a speckle image resulting from laser light interference. Speckle images are recorded using a borescope camera connected to a computer so that the recorded data can be directly stored in the computer. Fig. 1 shows the experimental setup for recording sandpaper speckle images.

B. Speckle Image Processing

Speckle image processing aims to obtain adaptive histogram features. These features will be used to identify the surface roughness of the sandpaper. Speckle image processing consists of three stages, namely pre-processing, image segmentation, and feature extraction. The pre-processing aims to improve the quality of the image. The image segmentation process in digital image applications is carried out by dividing the image into separate areas whose pixels are similar and have high contrast between areas. Image segmentation is intended to increase the ability to identify each digital image. Several parameters such as gray level, color, intensity, texture, and depth can be used to improve these capabilities. Histogram is an important parameter in digital image processing. Image histograms can be used to differentiate one image from another. Therefore, the features in the histogram can be used as a differentiator between one image and another [9, 10]. In this research, adaptive histogram features are used as characteristics in the image identification process. There are five features in the adaptive histogram, namely [11]:

1. Mean

$$\mu = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} P(i,j) \tag{1}$$

2. Variance

$$\sigma^2 = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(P(i,j)-\mu)^2 \tag{2}$$

3. Skewness

$$\alpha_3 = \frac{1}{MN\sigma^3}\sum_{i=1}^{M}\sum_{j=1}^{N}(P(i,j)-\mu)^3 \tag{3}$$

4. Kurtosis

$$\alpha_4 = \frac{1}{MN\sigma^4}\sum_{i=1}^{M}\sum_{j=1}^{N}(P(i,j)-\mu)^4 \tag{4}$$

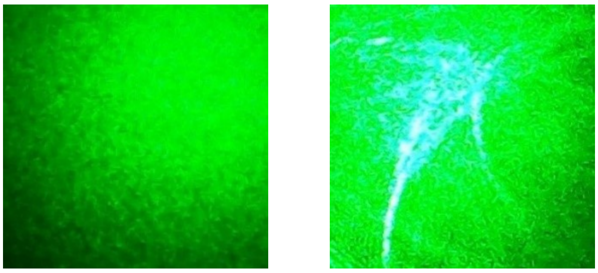
5. Entropy

$$E = -\sum_{i=1}^{M}\sum_{j=1}^{N} P(i,j)\log(P(i,j)) \tag{5}$$

Where M is the number of image pixel rows, N is the number of image pixel columns, and $P(i,j)$ represents the image matrix.

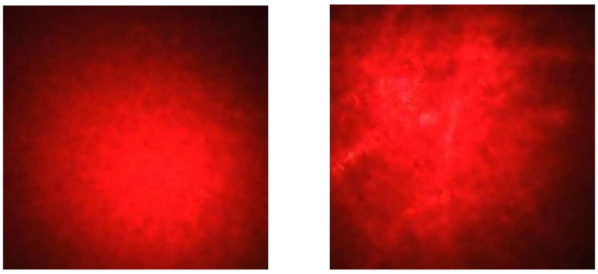
C. Identification Process Using Naïve Bayes Classifier

The Naïve Bayes method is an application of Bayes' Theorem that can be used for probabilistic-based prediction. One application of the Naïve Bayes method for prediction is in object identification. Two stages of the process must be carried out, namely the stages of the training and testing process. At this stage of the training process, a series of training data is



(a) (b)

FIG. 3: Image segmentation on first class (a) and second class (b) after irradiated by 550 nm light



(a) (b)

FIG. 4: Image segmentation on first class (a) and second class (b) after irradiated by 650 nm light

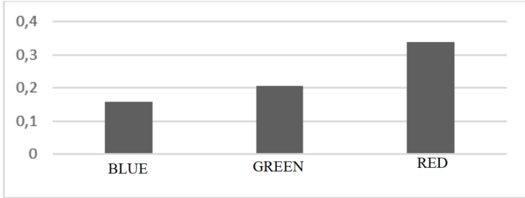


FIG. 5: Contrast value for wavelength spectrum in coarse paper

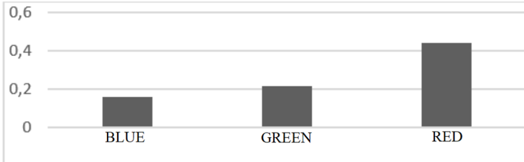


FIG. 6: Contrast value for wavelength spectrum in smooth paper

needed to obtain the mean and variance values for each feature of each class. Calculation of the mean value based on the equation:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{6}$$

Where n is the number of data and x_i is the i-th image for each feature and each class. The calculation of the value of variance (σ_2) is based on the equation:

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \mu)^2 \tag{7}$$

At this stage of the training process, the probability search for each image on feature X against class $Y = y$ is carried out based on the Gaussian distribution following the equation [12]:

$$P(X_i|Y = y) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{1}{2}\left(\frac{X_i - \mu}{\sigma}\right)^2\right] \tag{8}$$

III. RESULT AND DISCUSSION

The data used in this experiment are speckle patterns of coarse sandpaper and fine sandpaper which are irradiated with a red, green, and blue laser in jpg format with a size of 512x512 pixels. 84 images for sandpaper have been observed for speckle patterns. The 60 images are divided into first class and second class, each of which amounts to 30 as training data. Then there are 24 images which are divided into 12 images in each class. Initially, all images were standardized to a square size of 512x512 pixels. This stage aims to improve the quality of an image and retrieve the image before proceeding to the next stage. At this initial processing stage, there are several processes before the image is extracted for its feature values or features. The first process is the conversion of RGB images to greyscale. Converting RGB images to greyscale images aims to simplify the processing of image objects. The conversion process is carried out by obtaining the average value of the red, green, and blue values. This conversion process produces values on a gray scale from 0 to 255. The feature extraction process in this study uses the histogram equalization method.

Speckle imaging is a speckle technique that utilizes random patterns and interference from a light wave. This random pattern can be analyzed for various patterns that occur. In several decades several research methods have been developed with feature extraction using the histogram equalization method. In this study, the histogram equalization method was used as the feature extraction method using the Naïve Bayes Classifier.

The results of this study indicate that each wave has a significant effect on the wavelength. The interference pattern that occurs depends on the wavelength. So that the longer the wavelength used, the closer the distance between the dark and light patterns that occur. Fig. 2 shows an example of a sandpaper speckle image sample resulting from irradiation with a 405 nm laser diode. Fig. 3 shows an example of a sandpaper speckle image sample resulting from irradiation with a 550 nm laser diode. Fig. 4 shows an example of a sandpaper speckle image sample resulting from irradiation with a 650 nm laser diode. The interference phenomenon from the spectrum affects the average value of each image that is tested or trained.

TABLE I: The average value of each adaptive histogram feature of the blue speckle image

Feature	Smooth class	Coarse class
Mean	112.8405	122.3944
Variance	17.99937	19.25915
Skewness	-1.39477	0.045473
Kurtosis	51.90317	11.66125
Entropy	6.053297	6.215769

TABLE II: The average value of each adaptive histogram feature of the green speckle image

Feature	Smooth class	Coarse class
Mean	139.3634959	131.115
Variance	30.37360164	27.13022
Skewness	-0.224896874	-0.02368
Kurtosis	9.347246548	18.58814
Entropy	6.876712332	6.655505

Feature extraction using the adaptive histogram method provides feature extraction that varies between one feature for each sandpaper variation and wavelength variation. Feature extraction with this method contains 5 features, namely mean, variance, skewness, kurtosis, and entropy. The results of determining adaptive histogram features are shown in Table I for all blue speckle images, Table II for all green speckle images, and Table III for all red speckle images.

These three tables show that the identification value in recognizing the roughness of an object will increase as the light source increases. This is consistent with research conducted by Zhao that 532-nm lasers have advantages over 632-nm lasers [13]. So in terms of identifying objects, it will be more accurate if you use a light source with a lower wavelength. The contrast value decreases the smoother the sanding surface. Variations in the wavelength of the light spectrum show changes in the contrast value of the speckle image pixels. The contrast value referred to in this research is related to the gray contrast in the speckle image. This occurs due to the influence of wavelength where shorter wavelengths have a greater degree of gray so that the contrast value is greater. Fig. 5 shows the image contrast value of coarse sandpaper speckles for each wavelength of the laser light spectrum used. Meanwhile, Fig. 6 shows the image contrast value of fine sandpaper speckles for each wavelength of the laser light spectrum used. This is in accordance with research conducted by Postnov [8]. From the results of this research, it was found that the 632.8 nm laser was superior in detecting the main blood vessels on the surface of the mouse brain, while the 532 nm laser was superior in capturing small blood vessels in the mouse brain at a deeper depth. This may be due to the significant absorption ability of the 532 nm laser by major blood vessels [13]. Variations in the visible light spectrum influence the feature extraction results of the adaptive histogram method. An increase in the wavelength of the light spectrum causes an increase in the average gray level value of all pixels. Increasing this value will

TABLE III: The average value of each adaptive histogram feature of the red speckle image

Feature	Smooth class	Coarse class
Mean	62.56646	78.06906
Variance	27.59227	26.41881
Skewness	0.654215	0.112058
Kurtosis	7.056302	24.7098
Entropy	6.687873	6.659012

cause changes to the adaptive histogram feature extraction results. Changes in the results of feature extraction will cause changes in the results of the object roughness speckle image identification process. From the research results, it was found that the identification process would be more accurate if light with a shorter wavelength was used. The training accuracy is comparable to a study conducted by Novitasari in 2020 [10]. This study has several factors that influence this research. The contrast value in a pixel is affected by the homogeneity of a pixel. The higher the contrast, the more heterogeneous it will be so that the contrast becomes inhomogeneous while the smaller the wavelength the effect on the contrast. Later it will affect the gray contrast of an object [8]. Thus, light affects pixels through the homogeneity of the pixels and the average between pixels. Contrast C relation with wavelength λ and roughness R is given by:

$$C = 0.61\lambda - 0.0007R - 0.003 \quad (9)$$

Where R is given by:

$$R = \frac{1}{n}\sum_{i} y_i \quad (10)$$

The R-value indicates the level of roughness. A small R value indicates a rough surface, and vice versa a small R value indicates a smooth surface. Changes in the wavelength of light allow changes in the phase difference between two light beams. If the surface of an object has large roughness, there will be more interference phenomena between light rays so that more light and dark patterns will be produced. The increase in light and dark patterns will affect the contrast of the speckle image. Changes in the contrast of the speckle image will cause changes to the histogram of the speckle image. So the resulting histogram features will also change [14].

This research shows several things. That feature extraction is influenced by the spectrum of light irradiated on an object. The feature extraction can change due to the light captured. In addition to the geometry of the object. Waves below 650 nm have an advantage in terms of accuracy. This is by research research conducted by Youssef et al. in 2017 [15]. Thus, the process of identification or classification becomes easier. Thus, the nave Bayes classifier identification process is very dependent on the wavelength used in determining the roughness of objects. Where, the lower the wavelength, the smaller the pixel size, and the mean or homogeneity increases. Thus, the guess from the nave Bayes classifier will be more accurate with lower wavelengths.

IV. CONCLUSION

Variations in the visible light spectrum influence the feature extraction results of the adaptive histogram method. An increase in the wavelength of the light spectrum causes an increase in the average gray level value of all pixels. Increasing this value will cause changes to the adaptive histogram feature extraction results. Changes in the results of feature extraction will cause changes in the results of the object roughness speckle image identification process. From the research results, it was found that the identification process would be more accurate if light with a shorter wavelength was used. Identification accuracy increased from 92% to 96% due to the use of speckle images resulting from diode laser irradiation from 650 nm to 405 nm.

[1] P. G. Vaz, et al., "Laser Speckle Imaging to Monitor Microvascular Blood Flow: A Review," *IEEE Rev. Biomed. Eng.,* vol. 9, pp. 106120, 2016, doi: 10.1109/RBME.2016.2532598.

[2] E. Baradit, et al., "Surface roughness estimation of wood boards using speckle interferometry," *Optics and Lasers in Engineering,* vol. 128, p. 106009, May 2020, doi: 10.1016/j.optlaseng.2020.106009.

[3] F. Salazar and A. Barrientos, "Surface Roughness Measurement on a Wing Aircraft by Speckle Correlation," *Sensors,* vol. 13, no. 9, pp. 1177211781, Sep. 2013, doi: 10.3390/s130911772.

[4] L. Bruno, G. Parla, and C. Celauro, "Image analysis for detecting aggregate gradation in asphalt mixture from planar images," *Construction and Building Materials,* vol. 28, no. 1, pp. 2130, Mar. 2012, doi: 10.1016/j.conbuildmat.2011.08.007.

[5] T. De Goede, et al., "Droplet splashing on rough surfaces," *Phys. Rev. Fluids*, vol. 6, no. 4, p. 043604, Apr. 2021, doi: 10.1103/PhysRevFluids.6.043604.

[6] X. Zhao, L. Xue, and F. Xu, "Asphalt pavement paving segregation detection method using more efficiency and quality texture features extract algorithm," *Construction and Building Materials*, vol. 277, p. 122302, Mar. 2021, doi: 10.1016/j.conbuildmat.2021.122302.

[7] D. R. Patel and M. B. Kiran, "Non-contact surface roughness measurement using laser speckle technique," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 895, no. 1, p. 012007, Jul. 2020, doi: 10.1088/1757-899X/895/1/012007.

[8] D. D. Postnov, et al., "Choosing a laser for laser speckle contrast imaging," *Sci Rep*, vol. 9, no. 1, p. 2542, Feb. 2019, doi: 10.1038/s41598-019-39137-x.

[9] Ş. Öztürk and B. Akdemir, "Application of Feature Extraction and Classification Methods for Histopathological Image using GLCM, LBP, LBGLCM, GLRLM and SFTA," *Procedia Computer Science*, vol. 132, pp. 4046, 2018, doi: 10.1016/j.procs.2018.05.057.

[10] H. Mu'jizah and D. C. R. Novitasari, "Comparison of the histogram of oriented gradient, GLCM, and shape feature extraction methods for breast cancer classification using SVM," *J. Teknol. dan Sist. Komput*, vol. 9, no. 3, pp. 150156, Jul. 2021, doi: 10.14710/jtsiskom.2021.14104.

[11] D. C. R. Novitasari, et al., "Application of Feature Extraction for Breast Cancer using One Order Statistic, GLCM, GLRLM, and GLDM," *Adv. Sci. Technol. Eng. Syst. J.*, vol. 4, no. 4, pp. 115120, 2019, doi: 10.25046/aj040413.

[12] N. Zulpe and V. Pawar, "GLCM Textural Features for Brain Tumor Classification," vol. 9, no. 3, p. 6, 2012.

[13] Y. Zhao, et al., "Laser speckle contrast imaging system using nanosecond pulse laser source," *Journal of Biomedical Optics*, vol. 25, p. 11, 2020.

[14] V. R. Balaji, et al., "Skin disease detection and segmentation using dynamic graph cut algorithm and classification through Naive Bayes classifier," *Measurement,* vol. 163, p. 107922, Oct. 2020, doi: 10.1016/j.measurement.2020.107922.

[15] D. Youssef, et al., "Estimation of Articular Cartilage Surface Roughness Using Gray-Level Co-Occurrence Matrix of Laser Speckle Image," *Materials,* vol. 10, no. 7, p. 714, Jun. 2017, doi: 10.3390/ma10070714.