Chapter 8
Effect of Barnacle Fouling on Ship Resistance Using MATLAB Image Processing

Shaiful Bakri Ismail, Zulzamri Salleh, Mohd Faizal Abdul Razak, Aizat Khairi, Mohd Zaifulrizal Zainol, and Muhammad Azrin Muhammad Azhar

8.1 Introduction

Barnacles are attached to the hull of the ship and makes the ship to slow down and will result in 40% increases of fuel consumption (Demirel et al. 2017). This is because the barnacle fouling led to a loss of power for the ship to maintain at a constant speed thus increases of the fuel consumption. This statement also is supported (Alghamdi and Quijada 2019) in which it is stated that the ship that is covered by the barnacle will

S. B. Ismail (✉) · M. Z. Zainol
Marine Electrical and Engineering Technology Section, Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Jalan Pantai Remis, 32200 Lumut, Perak, Malaysia
e-mail: shaifulbakri@unikl.edu.my

M. Z. Zainol
e-mail: mzaifulrizal@unikl.edu.my

Z. Salleh · M. F. Abdul Razak
Maritime Engineering Engineering Technology Section, Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Jalan Pantai Remis, 32200 Lumut, Perak, Malaysia
e-mail: zulzamri@unikl.edu.my

M. F. Abdul Razak
e-mail: mfaizalar@unikl.edu.my

A. Khairi
General Study Department, Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Jalan Pantai Remis, 32200 Lumut, Perak, Malaysia
e-mail: aizat@unikl.edu.my

M. A. Muhammad Azhar
Maritime Management Section, Universiti Kuala Lumpur Malaysian Institute of Marine Engineering Technology, 32200 Lumut, Perak, Malaysia
e-mail: mazrin.azhr@s.unikl.edu.my

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utilize more fuel thus this research will provide an explanation and proves towards the problem stated by the past researcher. This research objective is to measure the growth rate of the barnacle by using image processing in MATLAB (Gerald and Maurice 2014) and to analyze the effect of barnacle fouling towards the ship performance. To achieve these objectives, a research question is provided which is how to measure the growth rate of the barnacle and how to analyze the effect of barnacle fouling on ship resistance and powering.

8.2 Literature Review

The term of fouling can be defined as the attachment of an organism on the surface of the hull whether the hull of the ship, boat or any kind of transportation that is floating on the surface of the sea water that can bring negative impact on the vessels. These organisms can also hide and live at the area in which the area is protected or niche such as the sea chest (Bressy and Lejars 2014). The fouling of the hull also can be called vessel fouling or biofouling. There are many kinds of example of organisms that are being attached on the surface of the hull such as the barnacle (Larsson et al. 2010; Sulaiman et al. 2018). The hull will be colonized by the organism whenever the vessels reach from one port to another port or bioregion to the next by means of invasions when these organisms release their larvae into the water (Desher 2018; Lau 2018).

There are several effects or impacts of the barnacle on the ship. Authors of Desher (2018) described that these barnacles are one of the examples of macrofouling organisms that accumulated and attached the hull in which it brings a very significant problem to the vessel's hull. Whenever these barnacles accumulate and increase their colony on the surface area of the hull, the hydrodynamic volume of the ship is increased thus the drag of the ship increases (Song et al. 2019). According to Bocchetti et al. (2015) the barnacle which is attached to the surface of the hull will causing the fuel consumption to increase.

The following are the formulae that are being used to calculate the ship resistance.

Total Resistance

The total resistance obtained four components which is the frictional resistance, residual resistance, air resistance and fouling resistance causing the resistance to occur on the ship during the movement of the ship through the water. Authors of Lau (2018), Birk (2019) indicate the equation for the total resistance.

$$R_T = R_{foul} + R_{aw} + R_{air} + R_{calm} \tag{8.1}$$

Frictional Resistance

The frictional resistance occurs when the water flows along the surface of the ships (Birk 2019). Equation (8.2) is the equation for the frictional resistance.

$$R_{aw} = WSA.f.V^{1.825} \tag{8.2}$$

Residual Resistance

The residual resistance is the pressure or force in which pushed the water aside (Birk 2019). The equation for this residual resistance is as Eq. (8.3).

$$Rv = C_v.(0.5).\rho.V^2.S \tag{8.3}$$

Air Resistance

The air flow that passes through or flows around the superstructure of the ship (Seok and Park 2020). Equation (8.4) shows the relation for air resistance.

$$R_{air} = (0.5)\rho SV^2 C_A \tag{8.4}$$

Fouling Resistance

The following is the formula for calculating the fouling resistance (8.5) of the ship by using the data gained from the image processing. Fouling is causing the ship to add more resistance towards the ship (Lau 2018).

$$Cfoul = Rfoul/\left(0.5.\rho.WSA.V^2\right) \tag{8.5}$$

8.3 Research Methodology

The images of the barnacle were taken each week and there is a total of three locations which is located at the KL Sauh UniKL MIMET. The images are the data for the image processing in MATLAB. The process of the image processing is shown in Fig. 8.1. Then, the data of the image processing will be the input to be used in the mathematical modelling realized using C++. The result is the resistance of the ship based on the coefficient of fouling.

8.3.1 Flowchart of Image Processing in MATLAB and C++ Programing

In MATLAB, the image processing tools are used to code the process of converting the image from the original image into black and white picture. From that black and white pixel picture, the images are analyzed by calculating the ratio between the

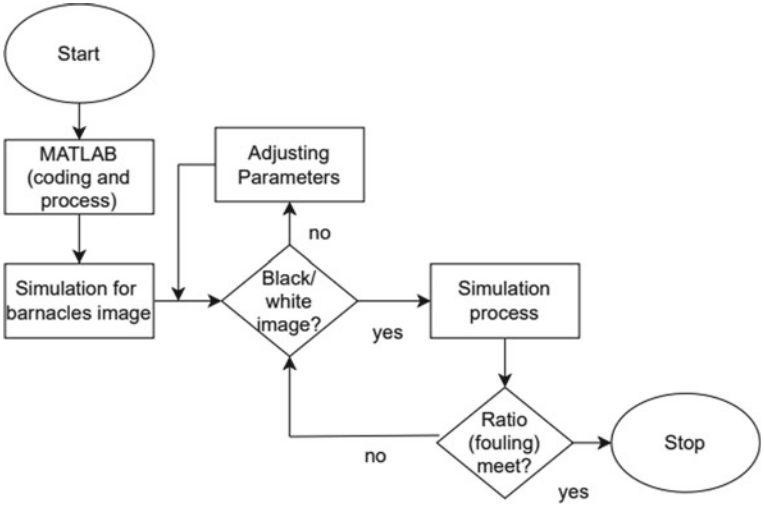

Fig. 8.1 Flowchart of MATLAB programming

black and white pixel to get the ratio as it represents as the coefficient of fouling. Meanwhile, by using C++ programming, the formula of the resistance is coded to get the result of the calculation based on the data of the ship and the data from the image processing in MATLAB which is the coefficient of fouling (Fig. 8.2).

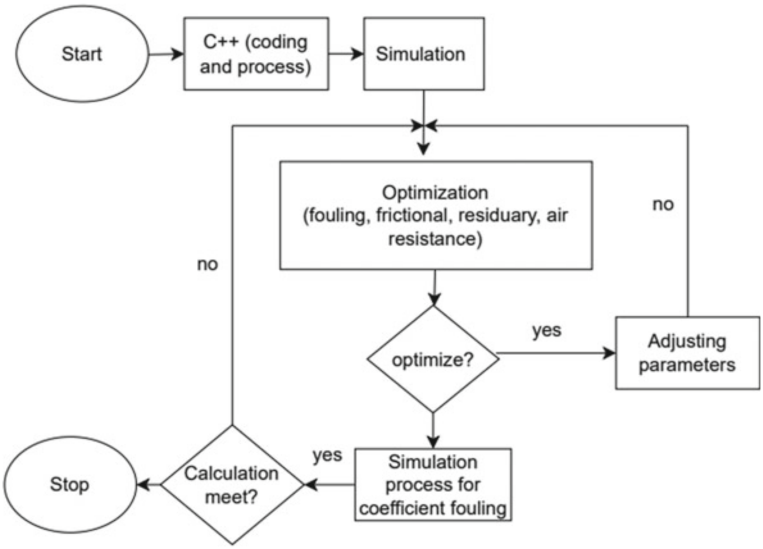

Fig. 8.2 Flowchart of C++ programming process

8.4 Results and Discussion

8.4.1 Raw Image of Barnacles

There is a total of four stages of image processing. Figures 8.3, 8.4, 8.5, 8.6, 8.7 and 8.8 are the result from the image processing MATLAB coding. Figure 8.3 shows the location 1 and location 2 of the barnacle image while Fig. 8.4 shows the image of location 3.

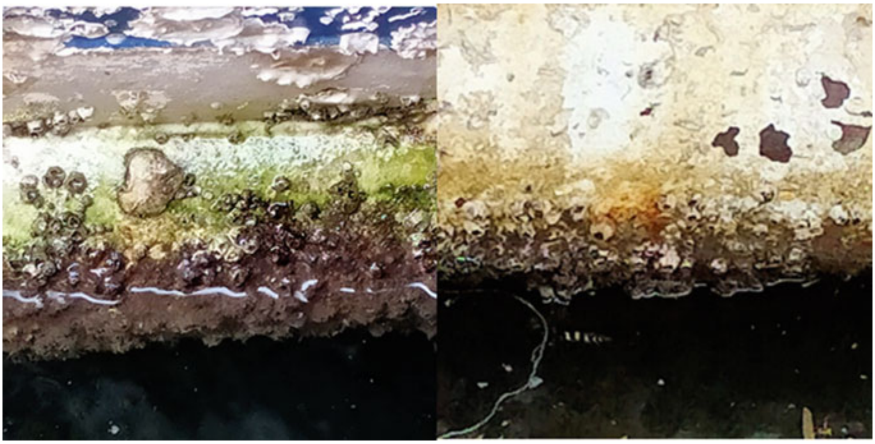

Fig. 8.3 Image at location 1 and location 2

Fig. 8.4 Image at location 3

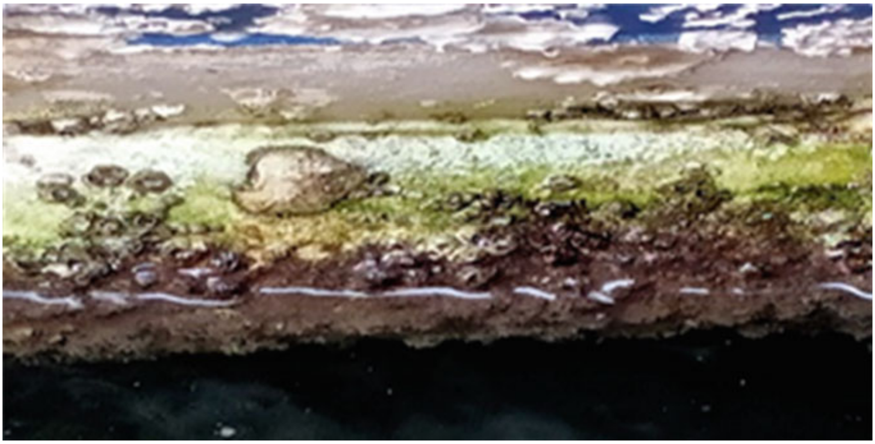

Fig. 8.5 Displaying image

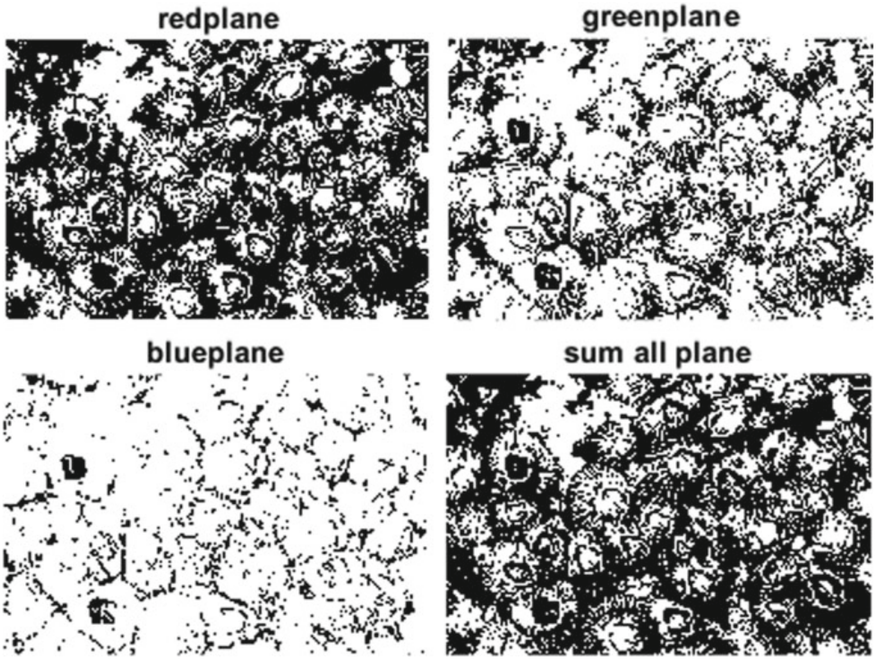

Fig. 8.6 RGB image

Fig. 8.7 Gray scaling image

Fig. 8.8 Final result of image

8.4.2 Image Processing of Barnacles

The first process is the displaying of the image taken which is the image of the barnacle. Figure 8.5 shows the original image that is being taken from each week and Fig. 8.6 shows each format of color into separate images. Each image of color format is then converted into grayscale and different types of color produce different image of grayscale as shown in Fig. 8.7. The result of the image is as shown on Fig. 8.8. The fouling coefficient, fouling resistance, total resistance and the effective power of the ship is tabulated, and a graph is plotted to analyze the result.

8.4.3 Result of Fouling Coefficient and Ship Resistance

This process calculates the total area of the image then the total of white pixel is divided with the total pixel area of the image to get the ratio of the white pixel. The white pixel result will be considered as the area of the barnacle or the coefficient of barnacle fouling. From Table 8.1, the value of the coefficient ratio which is the area of the barnacle compared to the area of the hull for location 1 is 0.6505 meanwhile location 2 and location 3 have a value of 0.5366 and 0.7443. This data is the initialization for the growth rate of the barnacle starting from week 5 which is considered as the first week of the barnacle image being taken until the final week which is in

Table 8.1 Result coefficient of fouling

Name of image	Coefficient ratio
Location 1	0.6505
Location 2	0.5366
Location 3	0.7443

week 12. The growth rate of the barnacle is monitored and analyzed each week in order to determine the growth rate of the barnacle.

The result from the image processing of each location of the barnacles is used as mathematical tabulated data in C++ programming. The results are shown in Table 8.2. Table 8.3 shows the result of growth rate per day for each location from week 5 until week 12 from three locations of barnacles. The area of barnacles represents the white number of pixels from the result of image processing (MATLAB). As for the coefficient of fouling, it is the ratio between the number of white pixels and black pixels. From Table 8.3, the coefficient of fouling significantly increases from 0.6505 to 0.7468. As a result, there is an increase of 14.8% for the barnacle growth rate at hull of the ship from week 5 until week 12 with a total percentage of 0.3% per day for location 1. Meanwhile, the coefficient of fouling growth rate is slightly increased for barnacles at location 2 and 3 are 0.2% and 0.04% per day, respectively.

8.4.4 Result of Fouling Resistance

The value of the fouling resistance at each different location is tabulated as shown on Table 8.4 and Fig. 8.9. Fouling resistance can be measured by using the value of fouling coefficient. The result for the fouling resistance will be divided into each location of the images which is fouling resistance for location 1, location 2 and location 3.

8.4.5 Result of Total Resistances

Table 8.5 and Fig. 8.10 show the total resistance of the ship in accordance to the barnacle growth rate at the hull of the ship which is the fouling coefficient. All the resistance occurring at the ship will be summed up such as the fouling resistance, air resistance, sea water pressure and water plane area pressure thus producing the total resistance of the ship. To analyze the impact of the fouling coefficient which is represent by the number of barnacles attached at the hull of the ship, the total resistance of the ship is calculated and estimated by using the mathematical modelling in the C++ software. There is an increase in percentage of the total average resistance up to 17.65–22.78% for three locations. This percentage of increase can be gained by doing the calculation of percentage increase. Location 2 stated the highest value of

Table 8.2 Result of estimation of resistance for each location

Location	Coefficient fouling	Fouling resistance	Sea water resistance	Air resistance	Area waterplane resistance	Total resistance	Effective power	% increase of resistance
1	0.6505	671.607	4.28153×10^{-10}	532.977	2061.81	3266.4	20,162.8	20.5611
2	0.5366	554.011	4.28153×10^{-10}	532.977	2061.81	3148.8	19,436.9	17.5943
3	0.7443	768.45	4.28153×10^{-10}	532.977	2061.81	3363.24	20,760.6	22.8485

Table 8.3 Result of fouling coefficient at all location until week 12

Week	Location 1	Location 2	Location 3
	Fouling coefficient	Fouling coefficient	Fouling coefficient
5	0.6505	0.5366	0.7443
7	0.5895	0.4103	0.7182
8	0.7014	0.5774	0.768
9	0.6872	0.5315	0.7234
10	0.7533	0.5528	0.7849
11	0.6934	0.5803	0.6956
12	0.7468	0.5897	0.7573

Table 8.4 Result of fouling resistance

Week	Location 1	Location 2	Location 3
	Fouling resistance (kn)	Fouling resistance (kn)	Fouling resistance (kn)
5	671.607	554.011	768.45
7	608.627	423.613	741.503
8	724.158	596.135	792.919
9	709.497	548.745	746.872
10	777.742	570.736	810.367
11	715.898	599.129	718.17
12	771.031	608.834	781.872

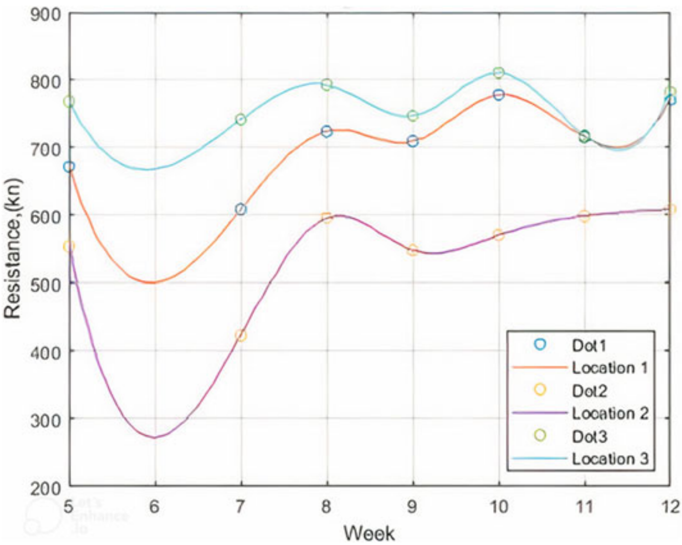

Fig. 8.9 Graph of fouling resistance

Table 8.5 Total resistance result

Week	Location 1	Location 2	Location 3
	Total resistance (kn)	Total resistance (kn)	Total resistance (kn)
5	3266.4	3148.8	3363.24
7	3203.42	3018.4	3336.29
8	3318.95	3190.93	3387.71
9	3304.29	3143.54	3341.66
10	3372.53	3165.53	3405.16
11	3310.69	3193.92	3312.96
12	3365.82	3203.63	3376.66

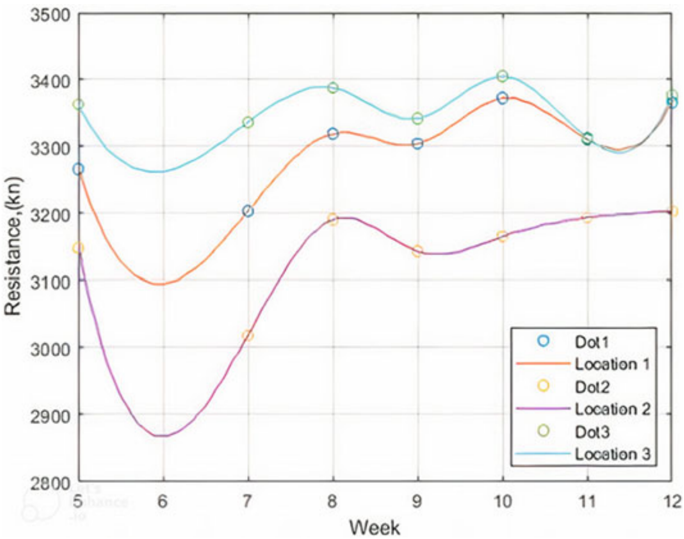

Fig. 8.10 Graph of total resistance

average resistance due to several reasons such as surface of the ship, seawater depth and reaction of organic substances.

8.5 Conclusion and Recommendation

In conclusion, both the objectives of this research are achieved which is to analyze the growth rate of the barnacle and to estimate the effect of the ship resistance caused by the barnacle fouling. Three different locations of barnacle image provide different values of growth rate and it shows that the barnacle grows for about 0.3021, 0.202

and 0.0356% per day. Hence, this barnacle growth brings impact to the increases of ship resistance for location 1 is about 21.49%, location 2 is 17.65% and location 3 is 22.78%.

Other than that from the result, the value of effective power is calculated and estimated so that the powering of the ship can be analyzed. The result indicated that the effective power significantly increases to 20,776.5 kW, 19,775.3 kW and 20,843.5 kW for each location respectively. There is an increase in percentage of the total resistance up to 20.56%. The ship structures that are covered by the barnacle will utilize more fuel and the fuel consumed by the delivery business is a huge supporter of worldwide carbon emission.

In the future, this result and scope can be widened which means not only calculated and estimated at the surface area of the barnacle but also consider the height of the barnacle. The data of these two different factors will be compared and the accuracy of the growth rate of the barnacle also the resistance of the ship can be further improved.

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Nomenclature

C_v	Coefficient of viscous resistance
ρ	Water density
V	Velocity
S	Wetted surface area of the underwater hull
C_v	Coefficient of viscous resistance
C_F	Tangential (skin friction) component of viscous resistance
R_n	Reynolds number
L	Length of ship
V	Velocity
v	Kinematic viscosity of water
Cfoul	Coefficient of fouling
Rfoul	Fouling resistance
ρ	Density of sea water
WSA	Wetted surface area
V	Velocity of the ship
R_{air}	Resistance of air
ρ	Density of air
C_A	Coefficient of air

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