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5 messages

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....
"The Application of endoscope and image processing for determining Remazol red dye concentration in water samples"

....

Abstract
Remazol dyes are widely used in textile industry which are then discharged to the environment as waste products. Studies on bioremediation and decolorization of dye waste normally employ expensive spectrometer or colorimeter. This study proposes a low-cost procedure to determine the concentration of Remazol red dye with the use of a digital endoscope and image processing technique. The concentration of Remazol red dye considered in this study ranges from 0.001 to 0.700 g/L. Endoscope is used to capture digital images of dye samples. Reg-green-blue (RGB) images of the samples are converted to grayscale images which are then converted to mean grayscale index (MGI). MGI are calibrated with real concentration of dye samples. Three calibration curves were developed for three different range of dye concentration 0.001- 0.010 g/L, 0.020 – 0.100 g/L and 0.100 – 0.700 g/L, with coefficient of determination (R2) of 0.961, 0.9793 and 0.9903, respectively.

Warm regards;

Professor Dr. Rosli Md Illias
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Jurnal
Teknologi

Full Paper

THE APPLICATION OF ENDOSCOPE AND IMAGE PROCESSING FOR DETERMINING REMAZOL RED DYE CONCENTRATION IN WATER SAMPLES

Nazatul Akmal Nazibudin, Mohamad Faiz Zainuddin*, Tengku Nur Adriana Tengku Nazruddin, Rona Techly Deny, Khairunnisa Kadaruddin

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Graphical abstract

Abstract

Remazol dyes are widely used in textile industry which are then discharged to the environment as waste products. Studies on bioremediation and decolorization of dye waste normally employ expensive spectrometer or colorimeter. This study proposes a low-cost procedure to determine the concentration of Remazol red dye with the use of a digital endoscope and image processing technique. The concentration of Remazol red dye considered in this study ranges from 0.001 to 0.700 g/L. Endoscope is used to capture digital images of dye samples. Reg-green-blue (RGB) images of the samples are converted to grayscale images which are then converted to mean grayscale index (MGI). MGI are calibrated with real concentration of dye samples. Three calibration curves were developed for three different range of dye concentration 0.001- 0.010 g/L, 0.020 – 0.100 g/L and 0.100 – 0.700 g/L, with coefficient of determination (R^2) of 0.961, 0.9793 and 0.9903, respectively.

Keywords: Remazol dye, endoscope, Image Processing, RGB, grayscale

Abstrak

Pewarna Remazol diguna secara meluas dalam industri pakaian yang akan dilepaskan ke alam sekitar sebagai bahan buangan. Kajian melibatkan bioremediasi dan penyahwarnaan pewarna buangan biasanya menggunakan spectrometer atau kolorimeter yang mahal. Penyelidikan ini mencadangkan satu prosedur kos rendah untuk menentukan kepekatan pewarna merah Remazol dengan menggunakan sebuah endoskop digital sebagai alat pengesan cahaya dan teknik pemprosesan imej. Kepekatan pewarna merah Remazol yang digunakan dalam penyelidikan ini berjulat daripada 0.001 kepada 0.700 g/L. Endoskop digunakan untuk menangkap gambar digital sampel pewarna. Imej merah-hijau-biru (RGB) sampel tersebut ditukar kepada skala kelabu yang kemudian ditukarkan kepada indeks purata skala kelabu (MGI). MGI ditentukur dengan kepekatan asal sampel pewarna. Tiga kurva kalibrasi dibangunkan daripada data yang diukur untuk tiga julat kepekatan pewarna 0.001- 0.010 g/L, 0.020 – 0.100 g/L and 0.100 – 0.700 g/L, masing-masing dengan pekali penentuan (R^2) 0.961, 0.9793 dan 0.9903.

Kata kunci: Pewarna Remazol, endoskop, pemprosesan imej, GRB, skala kelabu

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1.0 INTRODUCTION

Color is an important physical parameter of water quality other than turbidity, temperature, taste, odor and solids [1]. It also an important indicator of water pollution [2]. Natural water is essentially colorless with slight blue tint [3]. Color in water can be caused by many factors such as organic matters, metals, and industrial wastes [4, 5]. Apparent color of water is the result of colloidal suspension that can be isolated with filtration and often attributed to iron or dissolved plant tannins. True color of water, on the other hand, is due to dissolved chemical and organic substances that cannot be isolated with filtration [1,6].

Many modern standard methods for determining color of water and wastewater such as Method 8025, Method 2120B/C (EPA110.2/3) and ASTM D 1209 are adopted from Hazen method. These methods examine comparisons of spectrophotometer absorbance reading between water samples and platinum-cobalt solution at a specific wavelength between 410 and 465 nm. A spectrophotometer or a colorimeter is commonly used as an instrument to determine color of water since people's perception of color can be subjective and lacks sensitivity [7, 8].

However, the price of de-facto standard scientific instruments such as spectrometer, colorimeter and turbidimeter can be prohibitively expensive for low resource communities to carry out effective and continuous natural and wastewater quality monitoring [9, 10]. As reported in [11], the price of a table-top UV-Vis spectrophotometer (Cary 60 UV-Vis) can reach up to USD30,000 while the price of portable spectrophotometers (Hach) range from USD2000 to USD8000. The price of these instruments would be more expensive if one includes the cost of shipping, foreign exchange, sales fee or commissions, taxes, duties, and other factors.

For that reason, many recent studies in sensors and instrumentations focus on developing low-cost instruments and procedures to accurately determine the level of turbidity [12, 3, 14, 15] and color [11, 16, 17]. These innovations take advantage of inexpensive and widely available electronic and optical components such as LED, light sensor, printed circuit board (PCB), microcontroller and Arduino modules to minimize the cost. Containers housing these components as well as water sample holder or cuvette can be fabricated from various economical materials such as polylactic acid (PLA), nylon block and corrugated papers. Mobile applications and open-source technology are used to process and analyze sampling data to obtain desired measured values [18]. Besides being used as scientific field instruments, these low-cost devices can also be used for education and teaching purposes.

Past studies have shown that industries such as pharmaceutical, cosmetics, textile, and food utilize thousands of synthetic azo dyes in their manufacturing processes which are then discharged into water as waste products [19]. Even at low concentrations, dye wastes and their degradations products can pose health threats to living organisms including humans [20, 21]. Among widely used dyes in textile industries are Remazol dyes and they are subjects of interest in bioremediation of dye waste [22, 23]. In bioremediation studies, UV-Vis is commonly used to determine the percentage of decolorization of dye waste.

This study attempts to determine the concentration of Remazol red dye solution in water samples with a digital endoscope and image processing technique. This endoscope is considered in this study because it is inexpensive, and its small diameter allows it to be inserted inside a small opening of standard sample cuvette which hold the water samples. The main function of the endoscope is to detect light by capturing digital images of the water samples. The amount of light that enters the endoscope will impact the pixel value distribution of digital images obtained by the endoscope. On the other hand, image processing is used for image conversion and data analysis. This paper covers the procedure to acquire images of water-red dye mixture samples with an endoscope and the fitting model relating the pixel value and the concentration of the samples.

2.0 METHODOLOGY

2.1 Beer-Lambert and Fresnel's law

Many instruments to quantify water turbidity and color are based on Beer-Lambert law. Beer-Lambert law deals with the absorbance and reflectance of light by a medium such as a body of water which gives the medium (water) its apparent color. The suspended particles inside a body of water are mainly responsible for blocking and redirect light from transmitting through water. With the absence of suspended particle, which is the case with pure or very clean water, light transmission is largely uninterrupted or with little scattering. Hence, pure or very clear water is considered colorless. Light scattering, absorption and transmissions are dependent on many factors such as the size, shape, and composition of suspended particles as well as the wavelength of the incident light [24].

Besides light absorption and reflectance by a body of water, since 1950s, there has been a large number of studies dedicated towards understanding how suspended particles interact with light at the surface [25]. One recently published paper attempted at finding the relationship between refractive index and concentration of dye. The paper discovered that the refractive index of Brilliant Blue dye solution increases with increasing dye concentration [26]. The refractive index, according to Fresnel's equation, describe the amount of light reflected and transmitted into a medium when light is incident at the boundary between different media. According to Fresnel's law, normal incidence reflection at the interface between air and water sample is given as follows [27]:

$$R = \frac{(n_a - n_s)^2}{(n_a + n_s)^2} \tag{1}$$

where n_a and n_s are the refractive indices of air and the sample, respectively. The refractive index of air is assumed 1 while the refractive index of dye solution depends on types of dye, dye concentration and wavelength. As the value of n_s increase, the value of R is expected to increase as well due to increasing refractive-index mismatch between air and the sample.

2.2 Preparation of Remazol red dye samples

Remazol red dye was imported and procured from Germany. The water-soluble dye came in powder form. Red dye solutions were prepared by dissolving specific amount of red dye powder in one liter of hot distilled water. A total of 30 red dye-water mixture solutions were prepared ranging from 0.001 g/L to 3.0 g/L to determine the limitation of the system (Figure 1). The temperature of the samples was maintained at ambient temperature during the measurement. Notice that the color intensity or the saturations of the samples increases with increasing concentration. The absorption and reflectance of the dye samples were obtained with UV-Vis spectrophotometer (SHIMADZU UV-3600) at the Faculty of Science, Universiti Putra Malaysia (UPM).

2.3 Fabrication of cuvette holder

A lightproof cabin was fabricated to house the cuvette (Figure 2 and 3). The design came with a lid with a tiny hole to allow endoscope to be inserted inside the cabin; but without allowing light to enter the cabin through the hole. The material used to fabricate the cabin was corrugated paper which was then covered with black tape on the outside to ensure the entire wall is opaque to light [15, 28]. On the other hand, the inside wall of the cabin is painted

(a) 0.001 g/L – 0.01 g/L

(b) 0.02 g/L – 0.2 g/L

(c) 0.3 g/L – 3.0 g/L

Figure 1 Remazol dye-water mixture samples

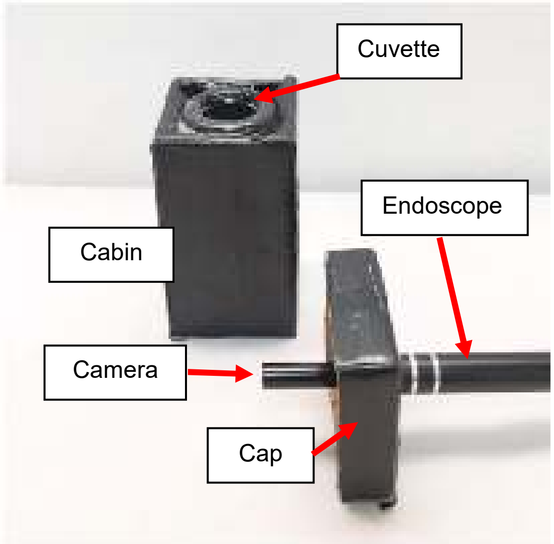


Figure 2 The cabin

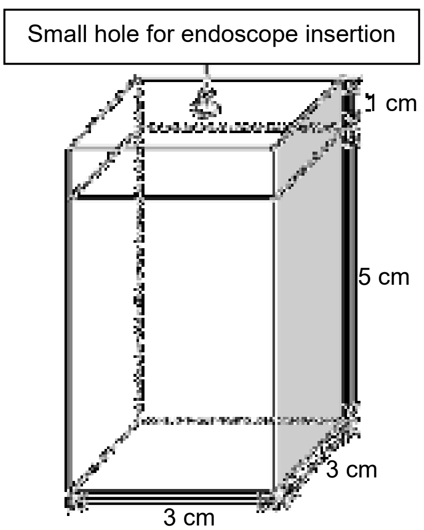


Figure 3 The dimension of the cabin

white to make sure the samples are visible to the camera. Corrugated paper was obtained at no cost because it was sourced from office waste. The cuvette used in this study is the standard sample cell 1 inch square glass 10 mL for Hach spectrometers as it is already available in the laboratory.

2.4 The setup of the endoscope

The endoscope used in this study is obtained from an online retailer. It is equipped with a digital camera and six small white LEDs equally spaced in a hexagonal configuration at the tip of the endoscope to illuminate the samples. Since the position of the camera (detector) is the same as the LEDs (light source), this effectively allows the camera to capture light reflected from water samples.

Table 1 **Specification of the digital endoscope used**

Features	Specifications
Resolution	1280 x 720/ 640.480 (5.5mm)
Lens diameter	5.5mm
Lamp	Adjustable LED light
Focal length	1.5cm to 2cm
Perspective	70
USB interface	Micro/USB

The intensity of light emitted from the LEDs is fixed for the whole measurement. The specification of the endoscope is given in Table 1. The tip of the endoscope is placed just above the surface of 10 ml red dye-water samples inside the cuvette to allow backscatter light measurement. The endoscope was connected to a personal computer to obtain the images of the samples. An application called "ViewPlayCap" (Figure 4) was installed to allow the computer to communicate with the endoscope. This application allows a user to view the samples in real time, snap images of the samples and save the images in a desired folder for further analysis.

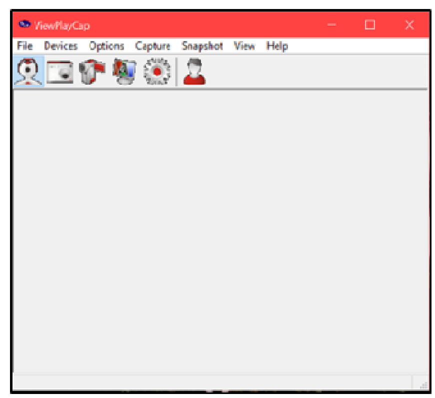


Figure 4 Display of "ViewPlayCap" Software

2.5 Image processing

Digital endoscope is considered in this study based on works reported in [12, 15, 28, 29] where digital camera and image processing were used to determine turbidity of water samples. Images of water samples were obtained from the camera mounted on the tip of the endoscope (Figure 2). Digital images consist of three vector components (u_1, u_2, u_3) for one image pixel (x,y) [30]:

$$C(x,y) = \left(u_1(x,y) \mid u_2(x,y) \mid u_3(x,y)\right)^T \quad (2)$$

$$C(x,y) = (u_1, u_2, u_3)^T \quad (3)$$

Quantity u denotes the integer pixel values between 0 and 255. The ranges for map coordinates x and y are $0 \leq x \leq M$ and $0 \leq y \leq N$ where M and N correspond to the resolution of the image $A = M \times N$. For red-green-blue (RGB) color space, each ***u*** corresponds to each color channel:

$$R(x,y) = u_1(x,y) \quad (4)$$

$$G(x,y) = u_2(x,y) \quad (5)$$

$$B(x,y) = u_3(x,y) \quad (6)$$

Only Red channel is selected due to the color of the dye considered in this study. Vector R is given as:

$$R = \begin{bmatrix} u(1,1) & u(1,2) & \cdots & u(1,n) \\ u(2,1) & u(2,2) & \cdots & u(2,n) \\ \vdots & \vdots & \ddots & \vdots \\ u(m,1) & u(m,2) & \cdots & u(m,n) \end{bmatrix} \quad (7)$$

where each $u(x,y)$ represents each pixel of the image red channel with coordinate x and y as mentioned earlier. The only pixels considered in this study is ones with pixel value of 255, which can be interpreted as the "brightest" or "whitest" pixel such that:

$$M = \sum_{j=1}^{z} 255(x,y)_j \quad (8)$$

Theoretically, as the amount of light entering the endoscope increases, it would produce an image with more pixels with value 255, hence the magnitude of M should increase.

3.0 RESULTS AND DISCUSSION

3.1 Absorption and reflectance of the dye samples

Figure 5 shows the absorbance and reflectance of selected dye-water mixture samples between 0.001 g/mL and 0.1 g/mL red dye concentration. It can clearly be seen that the absorbances are more significant in the 200-600 nm ranges which peak at approximately 510-520 nm range before drastically decrease near 600 nm. The 510-520 nm absorbance peak range is slightly lower than what is reported in other study (~540 nm) [31]. However, this is still within green spectrum (490-570 nm) which is expected for red dye UV-Vis light spectra. On the other hand, the reflectance plot reveals that samples with low dye concentration reflect most of the light across visible spectrum. In contrast, samples with high dye concentration samples effectively reflect light only in the red spectrum (600 – 800 nm). This is expected since, as shown in Figure 1, samples with low dye concentration are more clear and less "reddish" while samples with high dye concentration appear much darker to naked eyes.

3.2 Analysis of the sample images

Images of selected samples taken with the endoscope are shown in Figure 6. The cross marking seen in the images are drawn inside the cabin to guide the user to position the endoscope to be at the centre of the cuvette. The images clearly show that the apparent red intensity of the sample increases with increasing dye concentration which is already discussed earlier.

Another important observations to note here is thee presence of three reflections of the six LEDs of the endoscope; one on the surface of the water samples, and two at the bottom of the glass cuvette which can be clearly observed in the images as white markings. The white markings on the surface of the water samples appear larger as the red intensity of the samples increases. In contrast, the other white markings do not appear to change significantly with increasing dye concentration. This observation seems to suggest that more light is reflected from the surface of the water samples as dye concentration increases. As reported in [26], refractive index of dye solution increases with dye concentration. According to Equation (1), as refractive index increases, the reflection increases as well, which can explain the results shown in Figure 6.

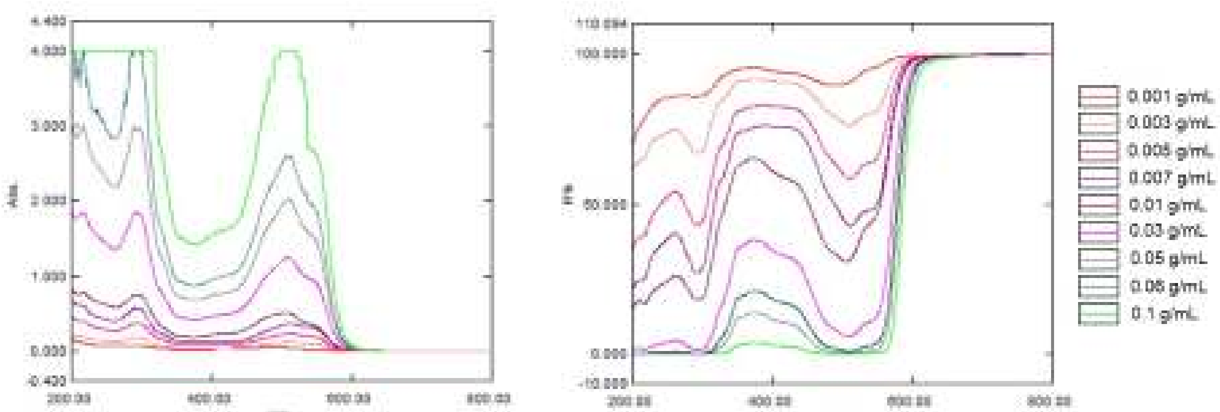
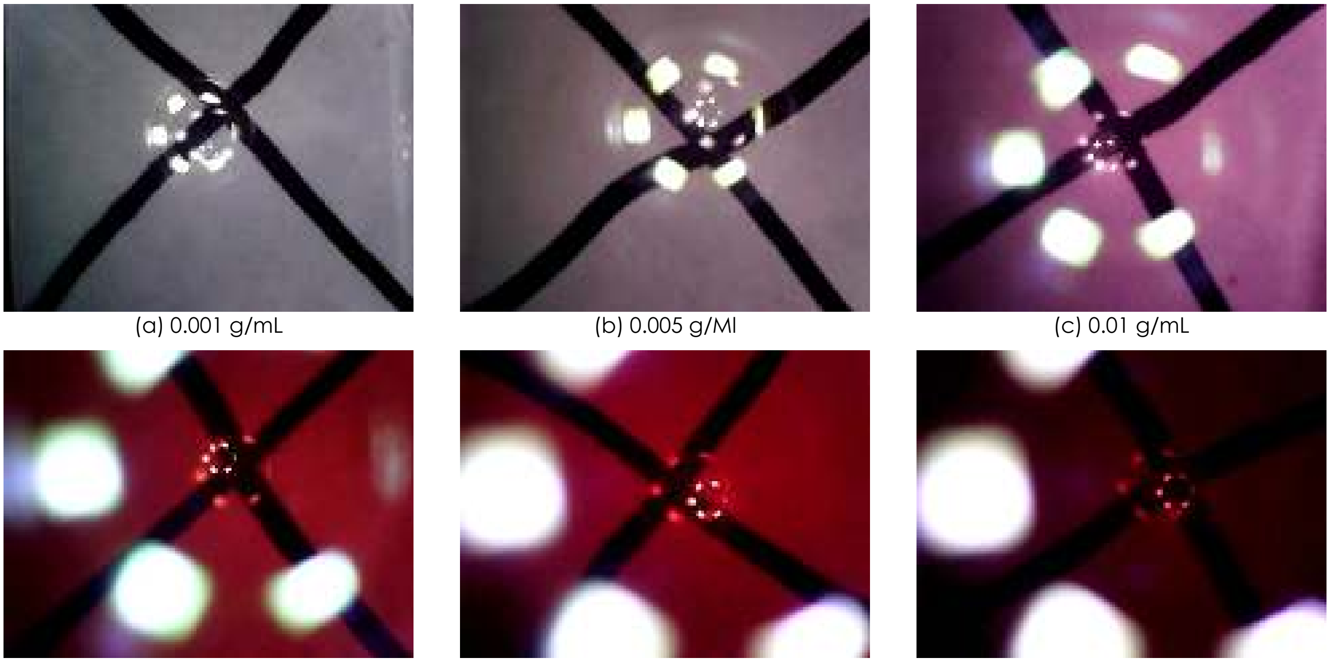


Figure 5 Absorbance (left) and reflectance (right) of selected red dye-water mixture samples.



(a) 0.001 g/mL (b) 0.005 g/Ml (c) 0.01 g/mL

(d) 0.05 g/mL (e) 0.1 g/mL (f) 1 g/mL

Figure 6 Selected images of dye-water mixture samples taken with endoscope.

3.3 Development of Fitting Models

A total of 26 out of 30 samples were used to develop the statistical relationship between pixel count (the values of M in Equation (8)). and measured concentration of red dye solutions. Four samples with dye concentration above 0.8 gm/L were rejected because it was found that the images obtained from these samples are not distinguishable from one another. This means the relationships between pixel count and dye concentration for these samples cannot be established. For all other samples, three images were obtained for each sample to obtain the mean and standard deviation of pixel count.

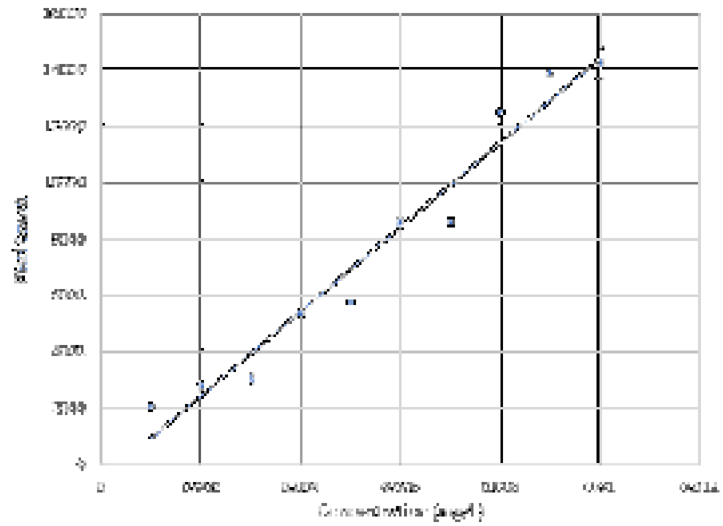
Figure 7 shows the relationship between pixel count and dye concentration. Three different regression models are developed to estimate dye concentration (D.C.) from measured pixel count (M) based on this relationship as given in Table 2. Note that these three models are needed for three different step-incremental ranges due to non-linear relationship between pixel count and dye concentration. The reliability of these fitting models is analysed in terms of coefficient of determination (R^2), root mean square error (RMSE) and normalized RMSE (NRMSE) [32]. Results in Table 2 offer several interpretations:

1. R^2 values, which highlight the predictability of these models and is the most useful indicator according to [33], shows that the third model (0.100 – 0.700 mg/L range) has the best fit as clearly observed in Figure 7.
2. RMSE emphasizes the significance of the outliers or the errors between predicted and observed values. RMSE seemingly suggesting that the third model contains more errors than the other two models. However, this is a little misleading since RMSE fails to take into account the large variance associated with large absolute errors as discussed in [34].
3. Therefore, NMRSE is presented here which is more suitable than RMSE in accounting for wide observed range of data. NMRSE results shown here are consistent with R^2 values to indicate that the third model is more reliable than the other two models in estimating D.C. from M.

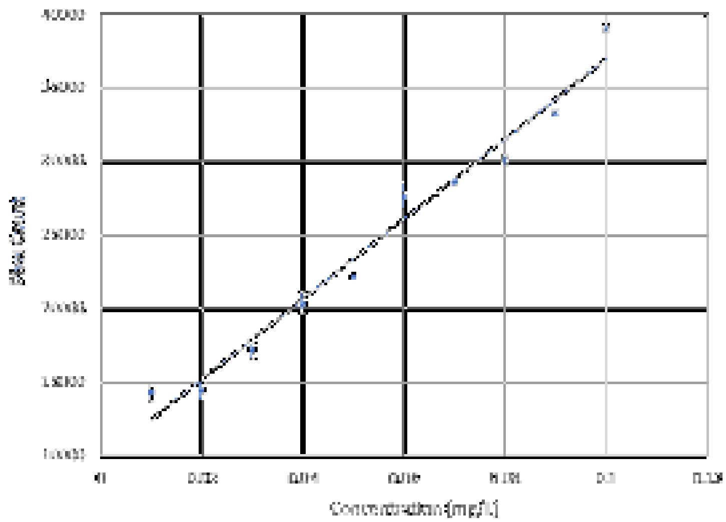
Table 2 **The performance of calibration equation relating dye concentration (D.C.) and pixel count (M)**

Calibration Equation	Range	Accuracy* (R^2)	RMSE*	NRMSE*
D.C. = **(**M + 555.44**)** ÷ 1499026.26	0.001 - 0.010 mg/L	0.961	0.001	0.105
D.C. = **(**M - 9718.00**)** ÷ 272254.00	0.010 - 0.100 mg/L	0.975	0.005	0.083
D.C. = **(**M - 37988.00**)** ÷ 15272.00	0.100 - 0.700 mg/L	0.987	0.023	0.058

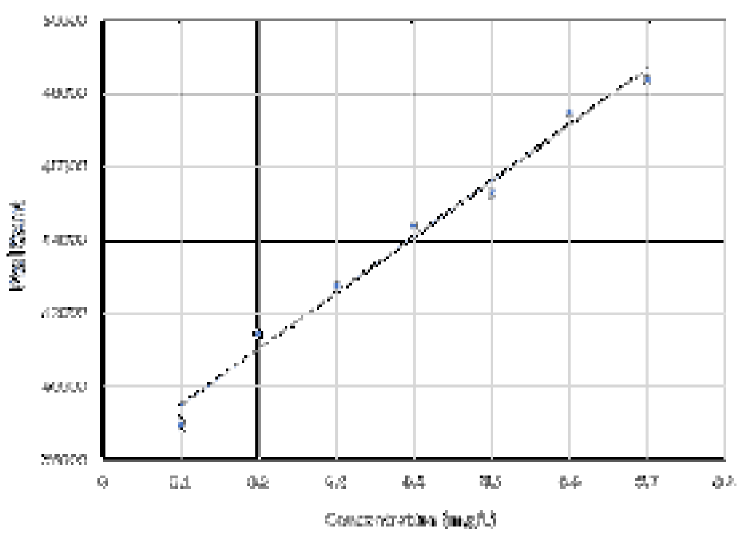
* calculated from [32]



(a) 0.001 mg/L – 0.01 mg/L range



(b) 0.01 mg/L – 0.1 mg/L



(c) 0.1 mg/L – 0.7 mg/L

Figure 7 Data fitting for three different ranges of dye concentration.

Based on these results, it can be clearly observed that the endoscope is more reliable at determining samples with higher dye concentration. Omar and MatJafri [24] noted that backscatter light configuration, as is the case with the endoscope, is less sensitive to detect low presence of suspended particles than other configurations. Another reason could possibly be due to fact greater amount of light is reflected to the camera for samples with higher dye concentration, resulting in better approximation of the concentration of dye.

Even though Chicco *et al*. [33] argues that R^2 = 0.80 indicates a "very good" fitting model, however, at least two recent studies in low-cost optical environmental sensors reported their fitting models as having R^2 values greater than 0.99 [35, 36]. Therefore, more works are needed to improve the fitting model. This include repeating the measurements to obtain more data and using sturdier material for the fabrication of the cabin. Employing artificial neural network (ANN) or convolution neural network (CNN) is another possibility to improve the fitting model.

In terms of cost, the endoscope is obtained in this study at the retail price of RM25.00 (~USD6.00). On the other hand, there is no cost incurred for fabricating the cabin since it was made with paper waste. Some similar studies reported the cost of their system while others chose not to disclose such information. For instance, Hoang *et al*. (2021) claimed that their system cost less than USD50.00 [35] while Khoshmaram and Mohammadi (2021) does not provide such information [36]. Therefore, for comparison, the cost of the system in this study is much less than the system demonstrated in [35].

4.0 CONCLUSION

This study covers the application of a low-cost digital endoscope and image processing in detecting Remazol red dye concentration in water samples. Three fitting models were developed to detect dye concentration ranging from 0.001 to 0.700 mg/L. The accuracy of these models are expressed in terms of determination of coefficient (R2), RMSE and normalized RMSE. This study demonstrated that a digital endoscope can be utilized as a low-cost light sensor to determine the concentration of Remazol red dye solution which can be useful in studies involving bioremediation and decolorization of dye waste. Besides dyes, it could also be possible to use the same instrument to detect and determine the presence of other suspended particles in water. However, more works are necessary to explore the potential of digital endoscope for such application especially for different analytes and solids.

Acknowledgement

This research was funded by Ministry of Higher Education Malaysia (MOHE), grant number KPM FRGS/1/2018/STG02/UPM/02/5 (FRGS 5540079).

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General comment

The paper provides an interesting study of a new method for determining Remazol red dye in water sample and contains new valuable scientific information. The title properly describes the contents of the performed work, and the abstract gives a brief description of methods and obtained results in a correct way. In my opinion, both the theory and the scope of the article are presented adequately. The statements in the paper are supported by well-arranged figures. The paper is structured well, and it is written in good English. Conclusions properly give a summary of results and perspectives.

Below are some comments and suggestions for improvement before this document is published.

1. Authors claim that this method is cheaper to manufacture than existing instruments. Is the instrument that has been made easier to use than the instrument that is commonly used?.
2. It has not been explained how much the sample volume is in the cuvette. 1/3, 2/3 or others. Is there any effect of the sample volume on the resulting image. Give an explanation.
3. Figure 6 shows an example of the resulting image from the measurement. Why the captured images have different magnifications.
4. Figure 7 made clearer.

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[Jurnal Teknologi] Article Review Acknowledgement "The Application of endoscope and image processing for determining Remazol red dye concentration in water samples,"

1 message

Professor Dr. Rosli Md Illias <journal_utm@utm.my> Wed, Jun 22, 2022 at 8:45 AM
To: bilalodin bilalodin <bilalodin@unsoed.ac.id>

Dear bilalodin bilalodin:

Thank you very much for completing the review of the submission,
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"The Application of endoscope and image processing for determining Remazol red dye concentration in water samples,"
----
for Jurnal Teknologi.

We appreciate your contribution to the quality of the work that we publish.

Warm regards;

Professor Dr. Rosli Md Illias
Chief Editor, Jurnal Teknologi
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