Monitoring Turbidity in Prai River Estuary Using Digital Camera Imagery

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Abstract- Turbidity distribution in river and coastal waters can be measured with optical remote sensing instruments. In this study, the feasibility of using digital camera imagery for estimating water turbidity using digital camera imagery in the Prai River estuary, Penang, Malaysia, was investigated. Digital camera imagery was acquired on 1st September 2003. The objective of this study is to evaluate the performance of our empirical turbidity retrieval algorithm for water turbidity mapping. Water samples were collected during a 3-hour period simultaneously with the airborne image acquisition above the study area. The colour image was separated into three bands (red, green and blue) for multispectral analysis. The samples were analyzed for turbidity measurement using a handheld turbidity meter. The algorithm used is based on the reflectance model which is a function of the inherent optical properties of water and this in turn can be related to the concentration of its constituents. The three-band algorithm was generated using the three visible bands namely red, green and blue bands. All the in situ data were used for algorithm calibration. The root mean square deviation (RMS) obtained in this study with this empirical algorithm was 1.19 NTU. We used the mosaic digital camera imagery to obtain a bigger study area. The result obtained indicated that reliable estimates of turbidity values for the Prai River estuary, Penang, Malaysia, could be retrieved using this technique.

Keywords- Turbidity, Remote Sensing, NTU, Airborne.

I. INTRODUCTION
Water quality monitoring is crucial for any effort to produce information in support of water conservation and decision-making. Monitoring normally needs to be carried out as cost-effectively as possible relative to the type of information needed [1]. Traditionally, monitoring of water quality is carried out through shipboard water sampling and laboratory analysis. Such methods are not only labour-intensive, but sampling is also discrete in time and space. Remote sensing offers an alternative method for monitoring water bodies on a large scale [2]. For example, the water quality study [3], algal blooms study [4], mineral mapping [5], plankton blooms study [6], haze study [7], phonological study [8], sediment and volcanic-hosted precious metal systems study [9], sea surface Sun-induced chlorophyll fluorescence [10], rice monitoring study [11], ocean colour and sea-grass study [12], sea surface temperature study [13] and land use study [14]. Remote sensing provides useful information for sediment transportation mapping in the coastal region [15]. Remote sensing can be used for various purposes. Satellite data analysis represents the most
suitable method for monitoring natural environments [16]. However, we used digital camera imagery captured from low altitude to overcome the problem of the difficulty in obtaining a cloud free satellite scene at Equatorial region.

Remote sensing techniques have been widely used for water quality studies in coastal regions and in inland lakes [17], [18], [19], [20], [21], [22], [23]. The purpose of the study was to assess the quality of airborne digital images for turbidity measurements of Prai River, Penang. Mostly, satellite data will be used for water quality monitoring, but the major disadvantage of satellite data is that, they cannot see through the clouds. Airborne digital camera imageries were selected in this present study because of several reasons. First, the airborne digital image provides higher spatial resolution data for mapping a small study area. Second, the airborne digital data acquisition can be carried out according to our planned surveys. The satellite observation times are fixed for a particular study area. Third, the digital imagery offers many advantages over film-based cameras. Furthermore, the study areas were located in the equatorial region where the sky is often covered by clouds. Therefore satellite remote sensing, especially for sensing in the visible and infrared regions is difficult. Water quality can be measured in various parameters, e.g. total suspended solids, chlorophyll, Secchi Disk, turbidity and etc. We used turbidity as our water quality parameter in this study. An algorithm was generated for retrieving turbidity distribution. A normal digital camera, Kodak DC290 was used as a sensor to capture images from a light aircraft, Cessna 172Q, at low altitude of 4400 feet.

**II. STUDY AREA**

The location of the study area is in the vicinity of the Prai river estuary, Penang. It is situated between latitudes 5º 22’ N to 5º 24’ N and longitudes 100º 21’ E to 100º 23’ E (Fig. 1). Images were taken during the flight between 9 a.m to 11 a.m on 1 September 2003. Turbidity readings were measured by using a handheld turbidity meter. Digital camera imagery was captured simultaneously during the acquisition of the water samples. Images were taken from a low altitude flying aircraft at 4400 feet. Water samples locations were determined using a handheld GPS.

**Fig. 1 The study area**

**III. WATER OPTICAL MODEL**

A physical model relating radiance from the water column and the concentrations of the water quality constituents provides the most effective way for analysing remotely sensed data for water quality studies. Reflectance is particularly dependent on inherent optical properties: the absorption coefficient and the backscattering coefficient. The irradiance reflectance just below the water surface, $R(\lambda)$, is given by

$$ R(\lambda) = 0.33b_b(\lambda)/a(\lambda) $$

where $\lambda$ is the spectral wavelength, $b_b$ is the backscattering coefficient and $a$ is the absorption coefficient [24]. The inherent
optical properties are determined by the contents of the water. The contributions of the individual components to the overall properties are strictly additive [25].

For the case of two water quality components, i.e. chlorophyll, C, and suspended sediment, P, the simultaneous equations for the two channels can be expressed as

\[ R(\lambda) = R_i = 0.33 \left( \frac{0.5b_{bw}(\lambda_i) + b_{bc}^*(\lambda_i)C + b_{bp}^*(\lambda_i)P}{a_{w}(\lambda_i) + a_{c}^*(\lambda_i)C + a_{p}^*(\lambda_i)P} \right) \]  (2a)

\[ R(\lambda) = R_i = 0.33 \left( \frac{0.5b_{bw}(\lambda_i) + b_{bc}^*(\lambda_i)C + b_{bp}^*(\lambda_i)P}{a_{w}(\lambda_i) + a_{c}^*(\lambda_i)C + a_{p}^*(\lambda_i)P} \right) \]  (2b)

where \( b_{bw}(i) \) is the backscattering coefficient of water, \( b_{bc}^*\) and \( b_{bp}^*\) are the specific backscattering coefficients of chlorophyll and sediment respectively, \( a_{w}(i) \) is the absorption coefficient of water, \( a_{c}^*(i) \) and \( a_{p}^*(i) \) are the specific absorption coefficients of chlorophyll and sediment respectively [26].

**IV. REGRESSION ALGORITHM**

Solving the above simultaneous equations (2a and 2b) for TSS concentration yields the series consisting of the terms \( R_1 \) and \( R_2 \)

\[ p = \frac{a_1 + a_2R_1 + a_3R_2 + a_4R_1R_2}{a_2 + a_3R_1 + a_4R_2 + a_5R_1R_2} \]  (3a)

\[ \Rightarrow p = \frac{A_1 + A_2R_1 + A_3R_2 + A_4R_1R_2}{A_2 + A_3R_1 + A_4R_2 + A_5R_1R_2} \]  (3b)

where \( a_j, j = 0, 1, 2, \ldots \) are the functions of the coefficients in equation (3b) which are to be determined empirically using multiple regression analysis. The algorithm can be extended to the three-band method as expected

\[
p = \frac{t_1 + t_2R_1 + t_3R_2 + t_4R_1R_2 + t_5R_1R_2R_3 + \ldots}{1 + t_1R_1 + t_2R_2 + t_3R_3 + t_4R_1R_3 + t_5R_2R_3 + \ldots}
\]

(4)

The higher order terms in Equation (4) have small values, so, Equation (4) can be approximated as Equation (5) for TSS.

\[
P = \frac{e_1 + e_2R_1 + e_3R_2 + e_4R_3}{1 + e_1R_1 + e_2R_2 + e_3R_3}
\]

(5)

Turbidity is a measurement of the decrease in transparency of stream water as light is scattered by suspended particulate matter [27]. Results from other studies have shown that turbidity measurements may correlate closely with sediment concentrations in streams. Research conducted by other studies showed a simple linear regression between turbidity and sediment measurements [28]. So, Equation (5) can be approximated as Equation (6) for turbidity (Tur).

\[
Tur = \frac{e_1 + e_2R_1 + e_3R_2 + e_4R_3}{1 + e_1R_1 + e_2R_2 + e_3R_3}
\]

(6)

The coefficients \( e_j, j = 0, 1, 2, \ldots \) are then empirically determined. This equation is used to relate reflectance values from the image bands to the observed turbidity concentrations. Processing of the digital camera data was carried out as follows. The original digital camera image was georeferenced. The image comprised three visible bands was saved as a *.tiff format image. In this study, we used digital number (DN) instead of reflectance values.

**V. DATA ANALYSIS AND RESULTS**

Image processing was performed in the School of Physics, Universiti Sains Malaysia using PCI Geomatica 10.1.3 software. The digital camera imagery acquired on 1\(^{st}\) September 2003 was high spatial resolution imagery with 480 pixels by
A total of eight digital images were mosaic to obtain a bigger study area (Fig. 3). The mosaic image was separated into three visible wavelength bands assigned as red, green and blue bands for multiband algorithm calibration.

The total number of turbidity measurement points corresponding to the simultaneous airborne data was 15. The mosaic image was rectified based on the image-to-image registration. The second order transformation polynomial was applied to resample the image using the nearest neighborhood method. The RMS error in rectification analysis was below 0.5 pixels. The digital numbers (DN) corresponding to the water locations were extracted for each bands. The DNs value extracted was used for algorithm calibration. The plot of the relationship between the DN’s for each channel and the turbidity values is shown in Fig. 4. The accuracy of the generated algorithm was examined based on the correlation coefficient (R), and root mean square deviation, (RMS). Fig. 5 shows the graph of the estimated and measured turbidity values using the generated algorithm.

Fig. 2 Raw images used in this study

Fig. 3 The mosaic image and the in situ water samples point

Fig. 4 Graph of digital numbers versus turbidity values

Fig. 5 Relationship between measured and predicted turbidity
The algorithm with three bands inputs, which gave a correlation value of 0.9757 and a standard error of 1.1931 NTU, is given by the following equation for turbidity:

\[
Tur = \frac{4.6033 + 0.2398R_1 - 0.4881R_2 + 0.3545R_3}{1 + 0.0053R_1 - 0.0278R_2 + 0.0217R_3}
\]

where \( R_1, R_2 \) and \( R_3 \) stand for the DNs of the digital camera red, green and blue bands respectively. The proposed algorithm was used to generate a turbidity map. In order to perform image analysis for water areas, the land areas were manually masked using Adobe Photoshop software. To reduce image noise an average filter of 3 by 3 window size was applied to the generated turbidity map. Finally, the turbidity map was colour-coded for visual interpretation (Fig. 6).

![Map of turbidity near Prai River Estuary](image)

**Fig. 6** Map of turbidity near Prai River Estuary [Blue = (< 10 NTU), Green = (10-20) NTU, Orange = (20-30) NTU, yellow = (30-40) NTU, Red = (>40) NTU, Brown = Land and Black = area outside image]

**VI. CONCLUSION**

This study showed that the generated algorithm produced accurate result for turbidity mapping. A bigger converge of study area can be obtained by mosaic several overlapped images. It also showed that a digital camera could provide useful remotely sensed images for water quality application.

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**REFERENCE**


