Algorithm for Haze Determination Using Digital Camera Images

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ABSTRACT

An algorithm for haze determination was developed based on the atmospheric optical properties to determine the concentration of particulate matter with diameter less than 10 micrometers (PM10). The purpose of this study was to use digital camera images to determine the PM10 concentration. This algorithm was developed based on the relationship between the measured PM10 concentration and the reflected components from a surface material and the atmosphere. A digital camera was used to capture images of dark and bright targets at near and far distances from the position of the targets. Ground-based PM10 measurements were carried out at selected locations simultaneously with the digital camera images acquisition using a DustTrak™ meter. The PCI Geomatica version 9.1 digital image processing software was used in all image-processing analyses. The digital colour images were separated into three bands namely red, green and blue for multi-spectral analysis. The digital numbers (DN) for each band corresponding to the ground-truth locations were extracted and converted to radiance and reflectance values. Then the atmospheric reflectance was related to the PM10 using the regression algorithm analysis. The proposed algorithm produced a high correlation coefficient (R) and low root-mean-square error (RMS) between the measured and estimated PM10. This indicates that the technique using the digital camera images can provide a useful tool for air quality studies.

Keywords: Algorithm, Atmospheric Optical properties, PM10, Digital Camera

INTRODUCTION

In recent years the use of remotely sensed data has found increasing applications in a wide range of environmental sciences and monitoring techniques (Gilabert et al. 1994). Remote sensing techniques can be used to estimate and map the concentrations of particulate matter in the atmosphere, providing both spatial and temporal information. Several studies have shown the possible relationships between satellite data and air pollution [Weber, et al., (2001) and Ung, et al, (2001a)]. Other researchers used satellite data such as NOAA-14 AVHRR (Ahmad and Hashim, 2002) and TM Landsat (Ung, et al., 2001b) in their studies. Air pollution is actually the addition of any harmful substances to the atmosphere, which causes the damaging of the environment, human health and the quality of life. Consequently, there has been an increase in the death rates resulting from various diseases caused by air pollution varying from breathing problem to lung cancer.
The atmosphere contains suspended particles, ranging in size from about $10^{-3}\mu m$ to about $20\mu m$, called aerosols. These aerosols are produced directly by natural processes and human activities. Natural aerosols include volcanic dust, sea spray, and its particulate product. Aerosols not only scatter but also significantly absorb the incoming solar radiation covering the entire spectrum. Air quality standards often refer to respirable suspended particulate matter (PM), being aerosols with a diameter smaller than $10\mu m$ (PM10) (UNEP).

The objective of this study is to investigate the feasibility of using digital camera data to estimate PM10 concentration using algorithm model. A Canon Power Shoot A70 digital camera was used as sensor to capture the digital camera imageries of certain targets at far and near distances. The PM10 were measured simultaneously with the acquisition of digital camera imageries using a DustTrak Aerosol Monitor 8520. This system is cheaper, economical and easy to operate.

**STUDY AREA**

The study area is the Penang Island, Malaysia, which is situated within latitudes 5° 12’ N to 5° 30’ N and longitudes 100° 09’ E to 100° 26’ E (Fig. 1). The corresponding PM10 measurements were collected at 83 selected locations around the Penang Island between 10:00 a.m. to 5:00 p.m. PM10 measurements were measured simultaneously with the acquired digital camera images. The locations were determined using a handheld Global Positioning System (GPS).

![Fig. 1: The location of the study area](image-url)
METHODS

In this study, we used a 1m x 1m black board as our reference target to calculate the PM10 and 1m x 1m white board as a reference to calculate transmittance in the atmosphere. We captured the digital images of the reference target by using the Canon Power Shot A70 digital camera in zoom mode setting at near and far distances from the target. The near and far distance between the target and the digital camera was 0.5m and 100m respectively. The camera axis was at 90° to the plane of the boards. The digital images were captured during a period of 10 days from 6 October 2007 until 25 November 2007 starting from 10:00 am to 5:00 pm simultaneously with the PM10 measurements using a DustTrak™ Aerosol Monitor 8520. PM10 measurements were taken at midway between the reference target and the digital camera for each selected station.

OPTICAL MODEL OF AIR

The suspended particles matter associated can significantly reduce visibility and can have detrimental health effects (Science Applications International Corporation, 2002). Several studies have shown mathematical relationships between satellite data and air pollution (Weber, et al., 2001). In this study, we were using a conventional digital camera to investigate the feasibility of using digital camera data to estimate PM10 concentration using a developed model. A new algorithm was developed based on the relationship between the reflected components from the targets and atmosphere.

Aerosols are formed by two main processes, a primary source which includes dispersion of material from the Earth's surface (like soil dust, sea salt particles, biomass burning, industrial debris) and a secondary source resulting from atmospheric chemical reactions on condensation or coagulation processes (Kaufman and Tenre, 1998). Fig. 1 shows an electromagnetic radiation path propagating from the sun towards the digital camera penetrating through the air pollutant column. (Modified after, Asmala and Hashim, 1997, and Lim et. al, 2005).

FIGURE 1. The Skylight Parameter Model.
In this study, an algorithm was developed for PM10 determination. According to Fig. 1, the recorded radiance (far distance image), \( L_t \), is given by:

\[
L_t = L_a + tL_s
\]  
(1)

where, \( L_a \) is atmospheric path radiance, \( L_s \) is the radiance from the surface, and \( t \) is a total transmittance from the surface to sensor. Eq. 1 can be converted to reflectance by dividing each term by the total incident radiance, \( L_i \). Then, we obtain:

\[
\rho_t = \rho_a + t\rho_s
\]  
(2)

where, \( \rho_t \) is a recorded reflectance, \( \rho_a \) is value of reflectance from atmospheric scattering, and \( \rho_s \) is the surface reflectance of the target (a constant value). From Eq. 1, and Eq. 2, the atmospheric reflectance can be derived as:

\[
\rho_a = \rho_s \left[ \frac{L_t - tL_s}{L_s} \right]
\]  
(3)

However, \( L_t \approx cDN_t \), and \( L_s \approx cDN_a \), where \( DN_t \) and \( DN_a \) are the recorded digital numbers (DNs) of the images when the sensor-target distance at 100m and 0.5m respectively. The constant, \( c \) is the radiometric calibration parameter. We can write Eq. 4 as:

\[
\rho_a = \rho_s \left[ \frac{DN_t - tDN_a}{DN_a} \right]
\]  
(4)

Here, we calculate the value of \( t \) in Eq. 4 by Eq. 5 and to simplify the computation analysis, we approximate the terms in the bracket of Eq. 4 as Eq. 6.

\[
t = \left[ \frac{DN_{fn}}{DN_{nw}} \right]
\]  
(5)

\[
\alpha = \left[ \frac{DN_{fn} - \frac{DN_{fw}}{DN_{nw}} \cdot DN_{nb}}{DN_{nb}} \right]
\]  
(6)
where, the function of $DN_{fw}$ and $DN_{nv}$ is the DN value from far and near distance from white target. $DN_{fb}$ and $DN_{nb}$ is the DN value from far and near distance from black target. In this study, we assumed that the images recorded by digital camera at near distance were not affected by the atmospheric effect.

**Regression Algorithm**

The past studies have indicated that reflectance, $\rho_a$, is linearly related to the PM10 concentrations [7]. Therefore, the three band regression algorithm used in this study can be written as:-

$$PM10 = e_0 + e_1\alpha_1 + e_2\alpha_2 + e_3\alpha_3$$  \hspace{1cm} (7)

where, $\alpha_i [i = 1, 2, 3]$ represents red, green and blue band respectively and $e_i [i = 0, 1, 2, 3]$ are the coefficients to be determined empirically.

**RESULTS AND DISCUSSION**

The PCI Geomatica version 9.1.6 digital image processing software was used in all images processing analysis. The captured images were then separated into three bands namely red, green and blue and their DN values were determined. For each band in each image, the raw DNs values over the boards were extracted and averaged. A special transformation using Eq. 6 was then performed to the data. The graph of PM10 ($\mu g/m^3$) values versus $\alpha_i$ is shown in Fig. 2 and the graph between estimated PM10 and measured PM10 is shown in Fig. 3.

![Figure 3](image3.png)  
**FIGURE 3.** PM10 ($\mu g/m^3$) Values versus $\alpha_i$.  

![Figure 4](image4.png)  
**FIGURE 4.** Estimated PM10 versus Measured PM10.
In this study, we assumed that the images recorded by digital camera at near distance were not affected by the atmospheric effect. The relationship between the atmospheric reflectance retrieved from Eq. 3 and the corresponding air quality data for the pollutant was proposed as indicated by Eq. 7. The regression algorithm was calibrated using a regression analysis.

Table 1 shows the correlation coefficient obtained using the generated algorithm. Superior result was produced by the proposed model, which achieved the highest correlation coefficient, R value of 0.8565 and the lowest RMS value of 0.0333μg/m³.

**TABLE 1.** Regression and RMS results using different tested algorithms.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>R</th>
<th>RMS (μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM10=e₀+e₁α₁</td>
<td>0.7812</td>
<td>0.0487</td>
</tr>
<tr>
<td>PM10=e₀+e₂α₂</td>
<td>0.7623</td>
<td>0.0542</td>
</tr>
<tr>
<td>PM10=e₀+e₃α₃</td>
<td>0.7122</td>
<td>0.0493</td>
</tr>
<tr>
<td>PM10=e₁α₁+e₂α₂</td>
<td>0.8025</td>
<td>0.0442</td>
</tr>
<tr>
<td>PM10=a₁α₁+e₂α₃</td>
<td>0.7823</td>
<td>0.0512</td>
</tr>
<tr>
<td>PM10=e₀α₂+e₃α₃</td>
<td>0.7664</td>
<td>0.0508</td>
</tr>
<tr>
<td>PM10=e₀+a₁α₁+a₂α₂</td>
<td>0.8098</td>
<td>0.0472</td>
</tr>
<tr>
<td>PM10=e₀+e₁α₁+e₂α₃</td>
<td>0.7832</td>
<td>0.0563</td>
</tr>
<tr>
<td>PM10=e₀+e₃α₂+e₃α₃</td>
<td>0.7622</td>
<td>0.0510</td>
</tr>
<tr>
<td>PM10=e₀+e₁α₁+e₂α₂+e₃α₃</td>
<td><strong>0.8565</strong></td>
<td><strong>0.0333</strong></td>
</tr>
</tbody>
</table>

**CONCLUSION**

In this study, a normal digital camera images were used for estimation of PM10 concentration using our developed algorithm. The algorithm produced a promising accuracy. The high correlation between reflectance from atmospheric scattering and PM10 values indicates the reliability of the generated algorithm. The results produced in this study indicate that the digital camera imageries are useful for the air quality studies.

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**REFERENCES**


