REMOTE SENSING OF PM10 CONCENTRATION MEASUREMENT BY INTERNET PROTOCOL CAMERA

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Commission VI, WG VI/4

KEY WORDS: PM10, Internet Protocol, USM Campus, Multispectral Algorithm, Root-Mean-Square Error

ABSTRACT:

Due to the high cost and limited number of the air pollutant stations in the each area, they cannot provide a good spatial distribution of the air pollutant reading over a city. The objective of this study was to test the potential of an internet protocol (IP) camera digital camera for determination of particulate matter less than 10 micron (PM10). This study provided information on air quality over USM campus area. In situ data were measured simultaneously with the acquisition of IP camera data for algorithm regression analysis. The digital image was separated into three bands assigned as red, green and blue for multispectral algorithm regression. The digital numbers were extracted corresponding to the ground-truth locations for each band and then converted to radiance and reflectance values. The digital numbers of the three bands were converted into irradiance and then reflectance. The atmospheric reflectance values was extracted from the satellite observation reflectance values subtrated by the amount given by the surface reflectance. The relationship between the atmospheric reflectance and the corresponding air quality data was determined using regression analysis. A new algorithm was developed for detecting air pollution from the digital camera images chosen based on the highest correlation coefficient, R and lowest root mean square error, RMS for PM10. The algorithm produced a high correlation coefficient, R and low root-mean-square error, RMS, between the measured and estimated air quality measurements. The preliminary results demonstrated that the IP digital camera imageries can be use to estimate PM10 measurements accurately at a relatively much cheaper cost compared with other techniques.

1. INTRODUCTION

Remote sensing can be used in the various purposes. In the past few years, there has been a growing interest in the used of remote-sensing systems for a regular monitoring of the earth's surface (Bruzzone and Prieto, 2002). Air pollution causes a number of health problems and it has been linked with illnesses and deaths from heart or lung diseases. Nowadays, air quality is a major problem in many developed countries and they having build up their own network for measuring the air quality levels. Malaysia also has build up our network for monitoring our environment. A network is composed of static measuring stations, which allow continuous measurements of air pollution parameters. Data are collected hourly which include five types of the air pollution constituently such as particulate matter less than 10 micron (PM10), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). This network is managed by Alam Sekitar Malaysia Sdn. Bhd. (ASMA), agency contracted by the Department of Environment Malaysia to measure air quality in the country. Normally, researchers have been using satellite images in their studies [Weber, et al., (2001) and Ung, et al, (2001)]. But the main drawback of satellite images is the difficulty in obtaining cloud-free scenes especially at the Equatorial region. This problem can be overcome by using airborne images.

In this study, we used high spatial resolution digital imageries for air quality estimation. We captured digital imageries using an internet protocol digital camera over the campus of the Universiti Sains Malaysia (USM). In-situ measurements of corresponding air pollution parameters collected simultaneously at the air pollution station in University Sains Malaysia, Penang, were needed for algorithm calibration. The air quality in situ data used in this study were measure using a handheld DustTrak meter. The proposed algorithm produced high correlation coefficient (R) and low root-mean-square error (RMS).

2. STUDY AREA

The selected air quality station is located in USM campus at longitude of 100^0 17.864' and latitude of 5^0 21.528' (Fig. 1). The site consists mainly of undulating land and has many assets that make it an ideal university campus. University Sains Malaysia (USM) is situated in the northeast district of Penang island (Figure 1 and Figure 2).

Figure 1. Air Quality Station Area, USM, Malaysia.

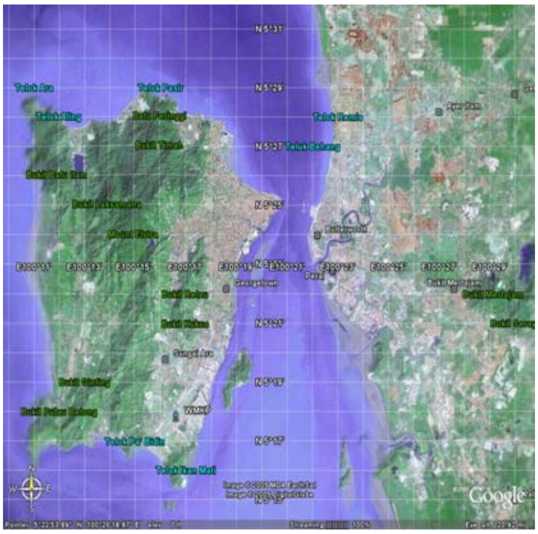

Figure 2. Study area in Pulau pinang, Malaysia.

3. METHODOLOGY

The digital images were captured on 6-10-2005 starting from 8.00 am. to 6.00 p.m. The digital images were captured hourly because the air quality data were also collected hourly.

The technique used in this study is based on a model developed by Asmala and Hashim (1997), which has been modified to make use of the skylight to indicate the existence of haze. Skylight is an indirect radiation, which occurs when the radiation from the sun being scattered by elements within the air pollutant column. Figure 3 shows electromagnetic radiation path propagating from the sun towards the digital camera penetrating through the air pollutant column. (Source: Modified after Ahmad and Hashim, 1997).

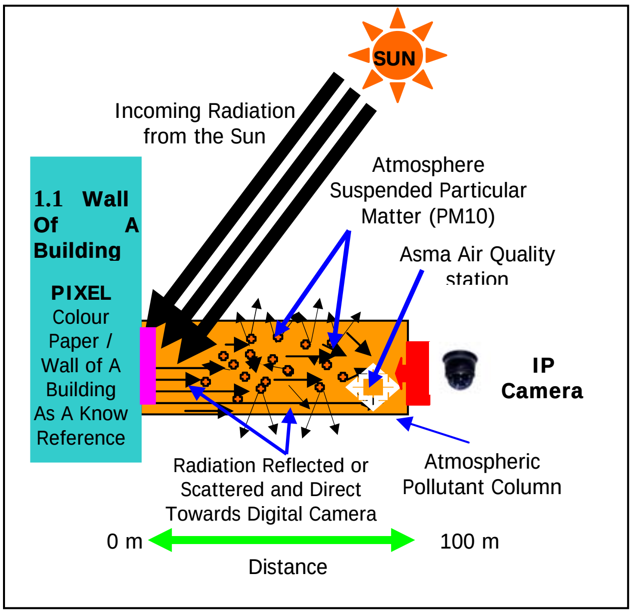

Figure 3. The skylight parameter model (Source: Modified after Ahmad and Hashim, 1997)

The modified model is described by:

$$Rs - Rr = Ra \tag{1}$$

where:
Rs = reflectance recorded by digital camera sensor
Rr = reflectance from know references
Ra = reflectance from atmospheric scattering

We use the wall of a building as our reference targets. The camera axis was at 90^0 to the plane wall of the building. We captured the digital images of the reference target by using the IP digital camera at a distance between the building and the camera was 100 meter. The air pollution station was located between the reference target and the digital camera.

4. ALGORITHM MODEL

The atmospheric reflectance due to molecule, R_r, is given by (Liu, et al., 1996)

$$R_r = \frac{\tau_r P_r(\Theta)}{4\mu_s \mu_v} \tag{2}$$

where
τ_r = Aerosol optical thickness (Molecule)
$P_r(\Theta)$ = Rayleigh scattering phase function
μ_v = Cosine of viewing angle
μ_s = Cosine of solar zenith angle

We assume that the atmospheric reflectance due to particle, R_a, is also linear with the τ_a [King, et al., (1999) and Fukushima, et al., (2000)]. This assumption is valid because Liu, et al., (1996) also found the linear relationship between both aerosol and molecule scattering.

$$R_a = \frac{\tau_a P_a(\Theta)}{4\mu_s \mu_v} \tag{3}$$

where

τ_a = Aerosol optical thickness (aerosol)
$P_a(\Theta)$ = Aerosol scattering phase function

Atmospheric reflectance is the sum of the particle reflectance and molecule reflectance, R_{atm}, (Vermote, et al., 1997).

$$R_{atm} = R_a + R_r \tag{4}$$

where
R_{atm}=atmospheric reflectance
R_a=particle reflectance
R_r=molecule reflectance

$$R_{atm} = \left[\frac{\tau_a P_a(\Theta)}{4\mu_s \mu_v} + \frac{\tau_r P_r(\Theta)}{4\mu_s \mu_v} \right]$$

$$R_{atm} = \frac{1}{4\mu_s \mu_v}\left[\tau_a P_a(\Theta) + \tau_r P_r(\Theta)\right] \tag{5}$$

The optical depth is given by Camagni and Sandroni, (1983), as in equation (6). From the equation, we rewrite the optical depth for particle and molecule as equation (7)

$$\tau = \sigma \rho s \tag{6}$$

where
τ = optical depth
σ = absorption
s = finite path

$\tau = \tau_a + \tau_r$ (Camagni and Sandroni, 1983).

$$\tau_r = \sigma_r \rho_r s \tag{7a}$$
$$\tau_p = \sigma_p \rho_p s \tag{7b}$$

Equations (7) are substituted into equation (5). The result was extended to a three bands algorithm as equation (8)

Form the equation; we found that PM10 was linearly related to the reflectance for band 1 and band 2. This algorithm was generated based on the linear relationship between τ and reflectance. Retalis et al., (2003), also found that the PM10 was linearly related to the τ and the correlation coefficient for linear was better that exponential in their study (overall). This means that reflectance was linear with the PM10.

$$R_{atm} = \frac{1}{4\mu_s \mu_v}\left[\sigma_a \rho_a s P_a(\Theta) + \sigma_r \rho_r s P_r(\Theta)\right]$$

$$R_{atm} = \frac{s}{4\mu_s \mu_v}\left[\sigma_a \rho_a P_a(\Theta) + \sigma_r \rho_r P_r(\Theta)\right]$$

$$R_{atm}(\lambda_1) = \frac{s}{4\mu_s \mu_v}\left[\sigma_a(\lambda_1) P P_a(\Theta, \lambda_1) + \sigma_r(\lambda_1) G P_r(\Theta, \lambda_1)\right]$$

$$R_{atm}(\lambda_2) = \frac{s}{4\mu_s \mu_v}\left[\sigma_a(\lambda_2) P P_a(\Theta, \lambda_2) + \sigma_r(\lambda_2) G P_r(\Theta, \lambda_2)\right]$$

$$P = a_0 R_{atm}(\lambda_1) + a_1 R_{atm}(\lambda_2) \tag{8}$$

Where
P = Particle concentration (PM10)
G = Molecule concentration
R_{atmi}= Atmospheric reflectance, i = 1 and 3 are the band number
a_j= algorithm coefficients, j = 0, 1, 2, … are then empirically determined.

5. DATA ANALYSIS AND RESULTS

The PCI Geomativa version 9.1.8 digital image processing software was used in all image-processing analysis. The digital images were captured on 6-10-2005 starting from 8.00 am. to 6.00 p.m using IP camera above the building (Figure 4). The digital images were separated into three bands (red, green and blue). The digital numbers were extracted and determined for each band.

Figure 4. The digital image used in this study.

All the DN values were converted into irradiance using equation 9, 10 and 11.The DNs were converted into irradiance using the digital camera coefficient calibrated for each band. And then the irradiances were converted to reflectance using the equation 12 for each band.

The calibrated digital camera coefficients are

$$y_1 = 0.0004x_1 + 0.0612 \tag{9}$$
$$y_2 = 0.0006x_2 + 0.0398 \tag{10}$$
$$y_3 = 0.0005x_3 + 0.0511 \tag{11}$$

where
y_1 = irradiance for red band ($Wm^{-2}\ nm^{-1}$)
y_2 = irradiance for green band ($Wm^{-2}\ nm^{-1}$)
y_3 = irradiance for blue band ($Wm^{-2}\ nm^{-1}$)
x_1 = digital number for red band
x_2 = digital number for green band
x_3 = digital number for blue band

A handheld spectroradiometer was used to measure the sun radiation at the ground surface. The reflectance values was calculate using equation (12) below.

$$R = \frac{y(\lambda)}{E_s(\lambda)} \tag{12}$$

where
y (λ) = radiance of each visible bands ($Wm^{-2}\ nm^{-1}$)
E_s (λ) = sun radiation at the ground surface using a hand held spectroradiometer ($Wm^{-2}\ nm^{-1}$)

After that, the reflectance recorded by the digital camera was subtracted by the reflectance of the known surface (equation 1) and we obtained the reflectance caused by the atmospheric components. The relationship between the atmospheric reflectance and the corresponding air quality data for the pollutant was carried out using regression analysis. The proposed algorithm produced the highest correlation coefficient between the predicted of 0.8523 and the measured PM10 values and lowest RMS value of 16.4098 $\mu g/m^3$ compared to the other algorithms.

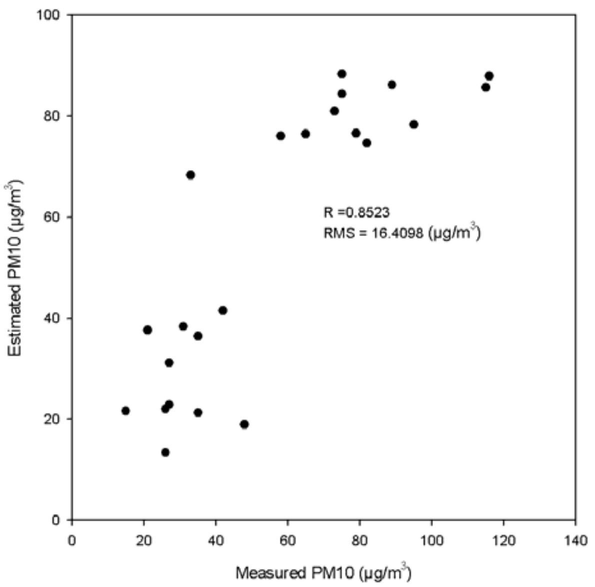

Figure 5. Correlation coefficient and RMS error of the measured and estimated PM10 ($\mu g/m^3$) value for calibration analysis

6. CONCLUSION

In this study, the IP digital camera imageries have been introduced for air quality estimation when produced a satisfying regression algorithm result. This proposed technique gives an alternative way to provide low cost digital imageries for environment atmospheric pollution application. The generated mathematical relations between PM10 with digital camera data produced an encouraging result. Further study must be carried out to increase digital camera capacity to estimates air quality.

7. ACKNOWLEDGEMENTS

This project was carried out using the USM short term grant. We would like to thank the technical staff who participated in this project. Thanks are extended to USM for support and encouragement.

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