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Development of Low Cost Air Quality Monitoring System by Using Image Processing Technique

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1. Introduction

Visual information of outdoor scenery portrays some important messages of atmospheric effects caused by light scattering, absorption and refractive-index fluctuations. These atmospheric effects are well related to some weather conditions such as air pollution, mist, haze, fog, rain and snow. In this digital age, images of outdoor scenes captured by digital camera can be processed digitally to determine these weather conditions.

In the last decade, the digital technologies have evolved at a continuously accelerating pace. This has fostered an incredible amount of research and development work on image processing technique. A number of image processing techniques are key elements of applied visual information research. In particular, image registration is a fundamental image processing technique, which has numerous applications to visual information research, in addition the more traditional application domains such as remote sensing. Other image processing techniques, such as image compression, are also relevant to the handling of large numbers of images for visual information research. Image Understanding refers to automated extraction of information from images.

In this study, we would like to develop a state-of-art image processing technique to enhance the capability of an internet video surveillance (IVS) camera for real time air quality monitoring. This technique is able to detect particulate matter with diameter less than 10 micrometers (PM10). An empirical algorithm was developed and tested based on the atmospheric characteristic to determine PM10 concentrations using multispectral data obtained from the IVS camera. A program is developed by using this algorithm to determine the real-time air quality information automatically. This development showed that the modern Information and Communications Technologies (ICT) and digital image processing technology could monitor air quality at multi location simultaneously from a central monitoring station.

2. The algorithm for image processing

In this study, we applied a unique image processing mechanism for air quality monitoring. This image processing mechanism was generated by our newly developed algorithm. We

developed this algorithm based on the fundamental optical theory, such as light absorption, light scattering and light reflection. This is a skylight model, which was developed to indicate the existence of particulate matter in the air. The skylight is an indirect radiation, which occurs when the radiation from the sun being scattered by elements within the air pollutant column. Figure 1 shows electromagnetic radiation path propagating from the sun towards the digital camera penetrating through the atmospheric pollutant column.
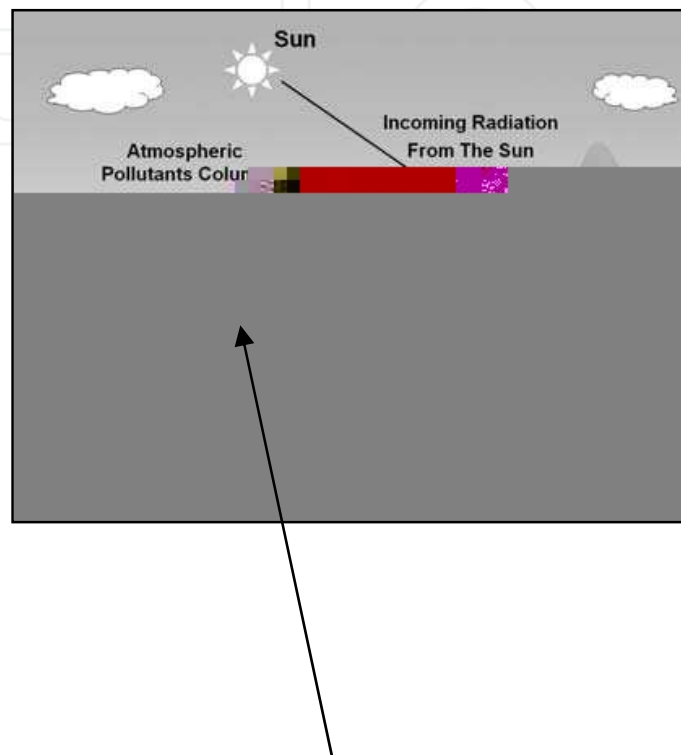

Fig. 1. The skylight parameter model to illustrate the electromagnetic radiation propagates from sunlight towards the known reference, and then reflected to propagate towards the internet surveillance camera penetrating through the interaction in atmospheric pollutant column.

Our skylight model described that the reflectance caused by the atmospheric scattering R_a was the reflectance recorded by the digital sensor R_s subtracted by the reflectance of the known references R_r.

$$R_a = R_s - R_r \tag{1}$$

In a single scattering of visible electromagnetic radiation by aerosol in atmosphere, the atmospheric reflectance due to molecules scattering, R_r is proportional to the optical thickness for molecules, τ_r, as given by Liu, et al. (1996) [10]. This atmospheric reflectance due to molecule scattering, R_r can be written as

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

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

By substituting equation (2) and equation (3) into equation (4), we obtain

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

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

The optical depth, τ given by Camagni and Sandroni, (1983) as expressed in equation (6), (7) and (8).

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

where

τ = optical depth
σ = absorption
s = finite path

$$\tau = \tau_a + \tau_r \tag{7}$$

$$\tau = \tau_a + \tau_r \tag{8}$$

Equations (7) and (8) are substituted into equation (5). The result was extended to a three bands algorithm as equation (9).

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

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

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

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

$$P = a_0 R_{atm}(\lambda_1) + a_1 R_{atm}(\lambda_2) \tag{9}$$

where

P = Particle concentration (PM10)
G = Molecule concentration
$R_{atm}(l_i)$ = Atmospheric reflectance, i = 1, 2 are the band number
a_j = Algorithm coefficients, j = 0, 1 are then empirically determined.

Equation (9) showed 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. In order to simplify the data processing, the air quality concentration was used in our analysis instead of using density, ρ, values.

3. Image processing methodology

3.1 Equipment set up

The remote monitoring sensor used in this air quality monitoring study is an Internet Video Surveillance (IVS) camera. This camera was used to monitor the concentrations of particles less than 10 micrometers in diameter. It is a 1.0 mega pixel Charge-Couple-Device CCD camera, allows image data transfer over the standard computer networks (Ethernet networks), internet. Figure 2 shows the IVS camera used in this study.

Fig. 2. Internet Video Surveillance (IVS) camera used in this study was installed at the top floor of School of Physics in Universiti Sains Malaysia.

Figure 3 showed the schematic set-up of the IVS camera used in this study. This set-up can provide a continuous, on-line, real-time monitoring for air pollution at multiple locations. It is used to capture outdoor images continuously, and these images can be processed by using our own developed algorithm. By using this image processing method, it is able to immediately detect the present of particulates air pollution, in the air and helps to ensure the continuing safety of environmental air for living creatures.
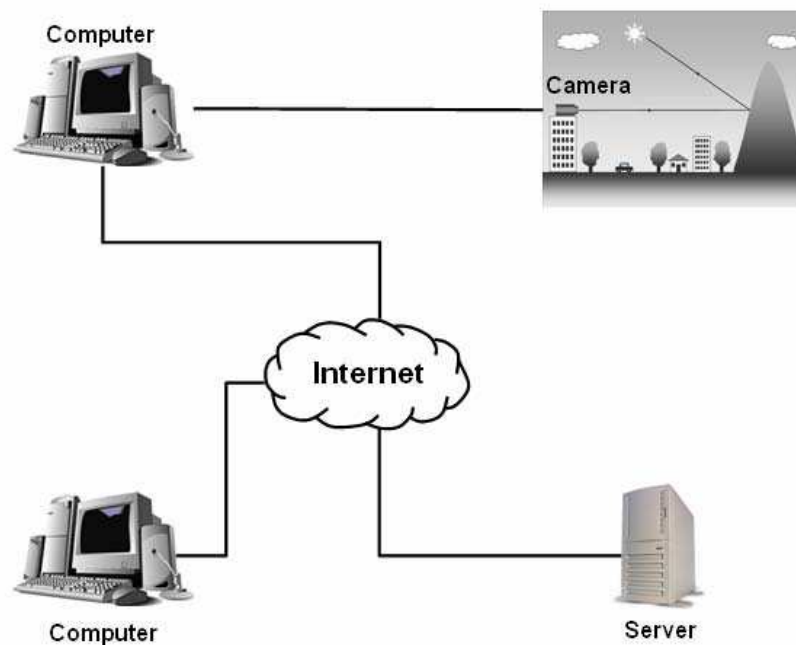
Fig. 3.The schematic set-up of IVS camera used as remote sensor to monitor air quality for this study

3.2 Study location

The camera was installed outside the wall of the Engineering Physics Laboratory at the top floor of School of Physics in the campus of Universiti Sains Malaysia at Penang, Malaysia. The location is at longitude of 1000°17.864' and latitude of 50°21.528' as shown in Figure 4, which is showed by the satellite map of the location to install the mentioned sensor. In this study, green vegetation is used as our reference target (Figure 4 & Figure 5).
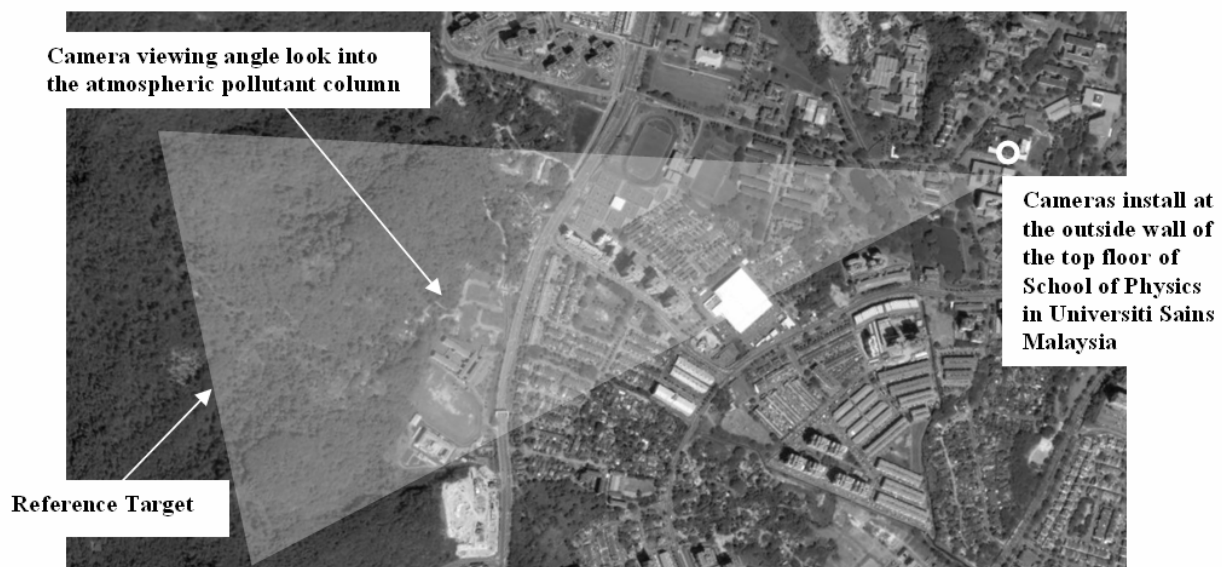

Fig. 4. The satellite image to show the location of internet video surveillance camera, which was installed outside the wall of Engineering Physics Laboratory in School of Physics at Universiti Sains Malaysia

4. Image processing and results

A sample of digital images captured by the internet video surveillance camera on 11 May 2007 from 8.00 am to 5.30 pm is showed in Figure 5. The target of interest is the green vegetation grown on a distant hill. These digital images were separated into three bands (red, green and blue). Digital numbers (DN) of each band for this target were determined from the digital images. The IVS camera can be calibrated by using an ASD handheld spectroradiometer, then we will obtain equations 10, 11 and 12. These equations were used to convert these DN values into irradiance.

The coefficients of calibrated digital camera are

$$y_1 = 0.0005x_1 + 0.0432 \tag{10}$$

$$y_2 = 0.0006x_2 + 0.0528 \tag{11}$$

$$y_3 = 0.0003x_3 + 0.0311 \tag{12}$$

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

Fig. 5.The digital image captured by internet video surveillance camera in this study, the reference target of green vegetation also shows in this photograph.

x_2 =   digital number for green band
x_3 =   digital number for blue band

An ASD handheld spectroradiometer was used to measure the sun radiation at the ground surface. The reflectance values was calculate using equation (13) below.

$$R = \frac{y(\lambda)}{E_s(\lambda)} \tag{13}$$

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

The reflectance recorded by the IVS camera was subtracted by the reflectance of the known surface (equation 1) to obtain the reflectance caused by the atmospheric components. The relationship between the atmospheric reflectance and the corresponding air quality data for the pollutant was established by using regression analysis. The correlation coefficient (R^2) between the predicted and the measured PM10 values, and root-mean-square-error (RMS)
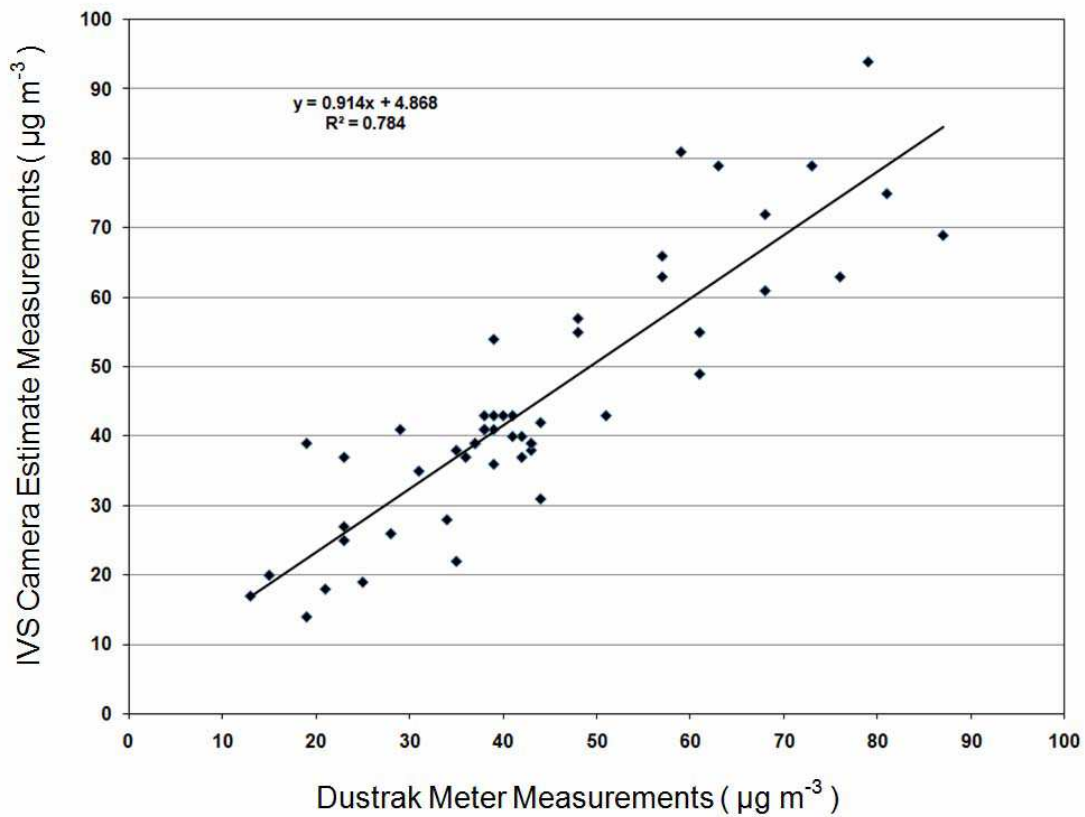
Fig. 6. Correlation coefficient and RMS error of the measured and estimated PM10 (µg/m3) value for calibration analysis on IVS camera
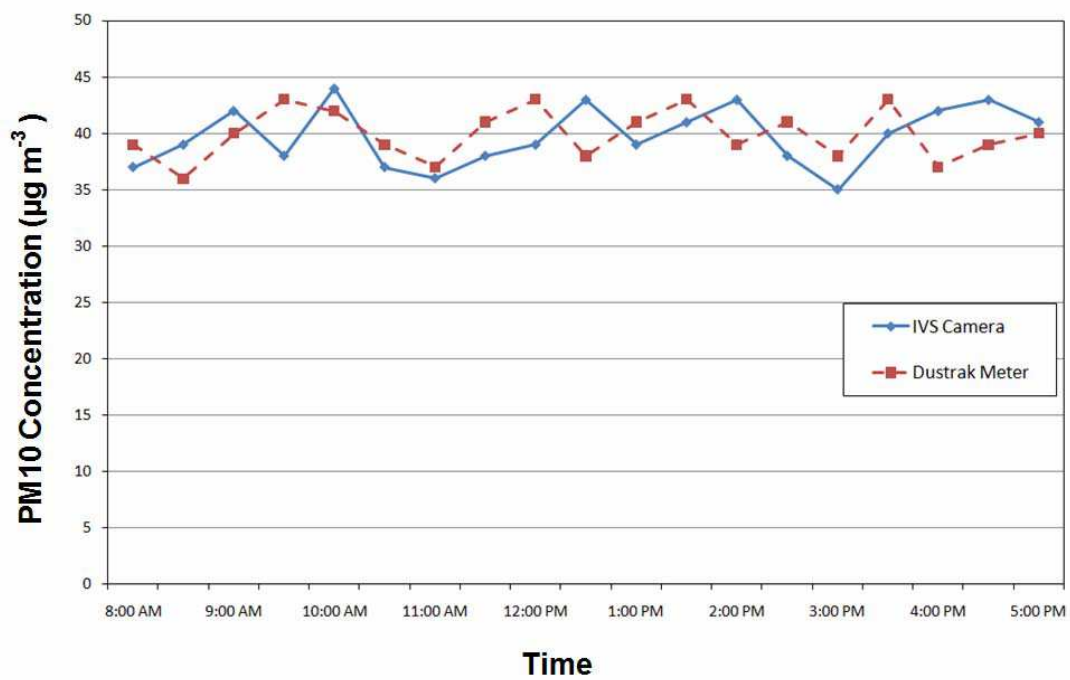

Fig. 7. Graph of PM10 concentration versus Time (11 May 2007)

value were determined. Figure 6 shows the correlation graph of the estimated measurement for IVS camera with the actual measurement from Dusttrak meter. The correlation coefficient (R^2) produced by the IVS camera data set was 0.784. The RMS value for IVS camera was ± 3 µg/m^3.

The temporal development of real time air pollution in a day measured by IVS camera and a Dusttrak meter is shown at Figure 7. The data were obtained on 11 May 2007 from 8.00am to 5.30pm.

5. Conclusion

Traditionally the air quality monitoring systems are involved with high set-up cost and also high operating cost. These have become the major obstacles for setting up more air quality monitoring systems at multi location. The purpose is to give an indicator to human for preventing the air quality become worst and worst. In this study, we have showed that the temporal air quality can be monitored by our own developed image processing technique. This technique is using the newly developed algorithm to process the image captured by the internet video surveillance camera. It produced real time air quality information with high accuracies. This technique uses relatively inexpensive equipment and it is easy to operate compared to other air pollution monitoring instruments. This showed that the IVS camera imagery gives an alternative way to overcome the difficulty of obtaining satellite image in the equatorial region and provides real time air quality information.

6. Acknowledgements

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There are six sections in this book. The first section presents basic image processing techniques, such as image acquisition, storage, retrieval, transformation, filtering, and parallel computing. Then, some applications, such as road sign recognition, air quality monitoring, remote sensed image analysis, and diagnosis of industrial parts are considered. Subsequently, the application of image processing for the special eye examination and a newly three-dimensional digital camera are introduced. On the other hand, the section of medical imaging will show the applications of nuclear imaging, ultrasound imaging, and biology. The section of neural fuzzy presents the topics of image recognition, self-learning, image restoration, as well as evolutionary. The final section will show how to implement the hardware design based on the SoC or FPGA to accelerate image processing.

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