UNIVERSITI SAINS MALAYSIA

DIGITAL ELEVATION MODELS (DEMs) STUDIES FOR AIR QUALITY RETRIEVAL FROM REMOTE SENSING DATA

DR. LIM HWEE SAN
PUSAT PENGAJIAN SAINS FIZIK
(304/PFIZIK/638103)

P 2948

UNIVERSITI SAINS MALAYSIA

LAPORAN AKHIR PROJEK PENYELIDIKAN JANGKA PENDEK
FINAL REPORT OF SHORT TERM RESEARCH PROJECT

Sila kemukakan laporan akhir ini melalui Jawatankuasa Penyelidikan di Pusat Pengajian dan Dekan/Pengarah/Ketua Jabatan kepada Pejabat Pelantar Penyelidikan

1. Nama Ketua Penyelidik: LIM HWEE SAN
Name of Research Leader

☐ Profesor Madya/ *Assoc. Prof.* ☑ Dr./ *Dr.* ☐ Encik/Puan/Cik *Mr/Mrs/Ms*

2. Pusat Tanggungjawab (PTJ):
School/Department

Pusat Pengajian Sains Fizik

3. Nama Penyelidik Bersama:
Name of Co-Researcher

Assoc. Prof. Dr. Mohd. Zubir Mat Jafri, Assoc. Prof. Dr. Khiruddin Abdullah and Mr. Nasirun Mohd. Saleh

4. Tajuk Projek: Digital Elevation Models (DEMs) studies for air quality retrieval from remote sensing data.
Title of Project

5. Ringkasan Penilaian/*Summary of Assessment*:	Tidak Mencukupi *Inadequate* 1	2	Boleh Diterima *Acceptable* 3	Sangat Baik *Very Good* 4	5
i) **Pencapaian objektif projek:** *Achievement of project objectives*				√	
ii) **Kualiti output:** *Quality of outputs*				√	
iii) **Kualiti impak:** *Quality of impacts*				√	
iv) **Pemindahan teknologi/potensi pengkomersialan:** *Technology transfer/commercialization potential*			√		
v) **Kualiti dan usahasama :** *Quality and intensity of collaboration*				√	
vi) **Penilaian kepentingan secara keseluruhan:** *Overall assessment of benefits*				√	

6. Abstrak Penyelidikan
(Perlu disediakan di antara 100 - 200 perkataan di dalam **Bahasa Malaysia dan juga Bahasa Inggeris**. Abstrak ini akan dimuatkan dalam Laporan Tahunan Bahagian Penyelidikan & Inovasi sebagai satu cara untuk menyampaikan dapatan projek tuan/puan kepada pihak Universiti & masyarakat luar).

Abstract of Research
(An abstract of between 100 and 200 words must be prepared in Bahasa Malaysia and in English). This abstract will be included in the Annual Report of the Research and Innovation Section at a later date as a means of presenting the project findings of the researcher/s to the University and the community at large)

Lampiran A

7. Sila sediakan laporan teknikal lengkap yang menerangkan keseluruhan projek ini. [Sila gunakan kertas berasingan]
Applicant are required to prepare a Comprehensive Technical Report explaning the project. (This report must be appended separately)

Lampiran B

Senaraikan kata kunci yang mencerminkan penyelidikan anda:
List the key words that reflects your research:

Bahasa Malaysia	*Bahasa Inggeris*
Model Ketinggian Betdigit	Digital elevation model (DEM)

8. Output dan Faedah Projek
Output and Benefits of Project

(a) * **Penerbitan Jurnal**
Publication of Journals
(Sila nyatakan jenis, tajuk, pengarang/editor, tahun terbitan dan di mana telah diterbit/diserahkan)
(State type, title, author/editor, publication year and where it has been published/submitted)

Lampiran C

(b) **Faedah-faedah lain seperti perkembangan produk, pengkomersialan produk/pendaftaran paten atau impak kepada dasar dan masyarakat.**
State other benefits such as product development, product commercialisation/patent registration or impact on source and society.

Lampiran D

* Sila berikan salinan/*Kindly provide copies*

(c) **Latihan Sumber Manus**
Training in Human Resources

i) Pelajar Sarjana:
Graduates Students
(Perincikan nama, ijazah dan status)
(Provide names, degrees and status)

Tan Kok Chooi, MSc, Graduated – 2010.

Joanna Tan Choay Ee, MSc, Ongoing

ii) Lain-lain:
Others

9. Peralatan yang Telah Dibeli:
Equipment that has been purchased

1. PCI Geomatica 10 – with ATCOR3

10/01/2011

Tandatangan Penyelidik *Signature of Researcher*	**Tarikh** *Date*

Komen Jawatankuasa Penyelidikan Pusat Pengajian/Pusat
Comments by the Research Committees of Schools/Centres

Diperakukan.

Assoc. Prof. Mohd. Zubir Mat Jafri
Deputy Dean
(Graduate Studies and Research)
School of Physics
Universiti Sains Malaysia
11800 Penang

TANDATANGAN PENGERUSI JAWATANKUASA PENYELIDIKAN PUSAT PENGAJIAN/PUSAT
Signature of Chairman
[Research Committee of School/Centre]

11/1/2011
Tarikh
Date

Digital Elevation Models (DEMs) studies for air quality retrieval from remote sensing

Final Report (304/PFIZIK/638103)

Research Endeavour and Accomplishment

by

Dr. LIM HWEE SAN

SCHOOL OF PHYSICS

UNIVERSITI SAINS MALAYSIA

Lampiran A

Abstract

Digital elevation model (DEM) generation from stereo images is an effective and economical method in topography mapping. This study used the stereo pair methodology to generate the digital elevation model (DEM) from PRISM (Panchromatic Remote-Sensing Instrument Satellite) sensor which is onboard of ALOS (Advanced Land Observing Satellite). The pair of forward-backward is used as stereoscopic imagery in this study. Ten ground control points (GCPs) are collected with residual error 0.49 pixels to generate an absolute DEM. This generated DEM with 2.5m spatial resolution is then matched with the 90m spatial resolution of SRTM (Space Shuttle Radar Topography Mission) DEM to compare the result. Although SRTM-DEM has a much courser resolution, the positional accuracy of the matching is found. The difference of the height from the mean sea level (MSL) between the SRTM-DEM and the PRISM-DEM is analyzed and the correlation between the two DEMs is R^2=0.8083. The accuracy of the DEM generated is given by the Root-Mean-Square Error (RMSE) value of 0.8991 meter. Besides that, the generated DEM data also will be used for the ATCOR3 analysis. In the air quality studies, the key issue in retrieving atmospheric reflectance from remotely sensed data is to identify the surface reflectance. In this study, the surface reflectance was created using ATCOR3 associated with the accurate DEM data. The atmospheric reflectance was obtained by subtracting the reference reflectance from the total reflectance observed by the digital images. And then the atmospheric reflectance can be related to the particles measuring 10µm or less (PM10) by using the regression algorithm analysis. Then the retrieved atmospheric reflectance values are used for regression analysis to determine the relationship between atmospheric reflectance and PM10 concentration.

Abstracts

Penjanaan Model Ketinggian Berdigit (DEM) daripada imej stereo merupakan satu kaedah yang berkesan dan ekonomi dalam pemetaan topografi. Kajian ini menggunakan metodologi pasangan stereo bagi menjanakan DEM daripada pengesan PRISM (Panchromatic Remote-Sensing Instrument Satellite) yang terletak di dalam satelit ALOS (Advanced Land Observing Satellite). Pasangan maju ke hadapan dan ke belakang digunakan sebagai imej stereoskopik di dalam kajian ini. Titik kawalan bumi (GCP) diambil dengan ralat 0.49 piksel untuk menjanakan satu DEM muktlak. DEM yang dijanakn dengan peleraian ruang 2.5 meter dibandingkan dengan DEM SRTM (Space Shuttle Radar Topography Mission) yang mempunyai peleraian ruang 90 meter. Walaupun DEM-SRTM mempunyai peleraian ruang

yang lebih rendah tetapi perbandingan kejituan posisi didapati. DEM dianalysis dan korelasi di antara kedua-dua DEM adalah R^2=0.8083. Kejituan bagi DEM yang dijanakan diberikan oleh nilai Sisihan Punca Min Kuasa Dua (RMSE), 0.8991. Selain itu, DEM yan dijanakan digunakan untuk kegunaan analysis ATCOR3. Dalam kajian kualiti udara, kunci utama dalam pendapatan pantulan atmosfera daripada data penderiaan jauh adalah penentuan pantulan permukaan. Dalam kajian ini, pantulan permukaan adalah dijanakan dengan menggunakan ATCOR3 dengan bantuan kejituan data DEM. Pantulan atmosfera didapatkan dengan menolakkan pantulan rujukan daripada jumlah pantulan bagi imej digital. Kemudian nilai pantulan atmosfera yang didapati bolehkan kaitkan dengan partikel bersaiz 10µm atau kurang *(PM10) dengan menggunakan analysis algoritma regresi. Nilai pantulan atmosfera yang didapati adalah digunakan untuk analysis regresi bagi menentukan hubungan antara pantulan atmosfera dan kepekatan PM10.*

Lampairan B

I. INTRODUCTION

A Digital Elevation Model (DEM) is digital data in which each point represents X-, Y- and Z- coordinates or latitude, longitude and height describing the bare soil. Extraction of accurate DEMs is important for flood planning, map generation, three-dimensional GIS, erosion control, environmental monitoring and others. The accuracy of DEMs based on space images is mainly depending upon the image resolution, the height-to-base-relation and the image contrast. Currently, several different technologies are being used to generate large area DEMs at various resolutions and accuracies, each with their own various resolution and limitation.

One main application of SAR is the generation of Digital Elevation Models (DEM). The Shuttle Radar topography Mission (SRTM) is widely considered to be the most successful SAR mission up to date. The DEM of almost global coverage derived from data gathered during this mission are still used as elevation model for many applications in various fields such as geoscience and civil engineering. However, the spatial grid of the DEM is about 30 m or 90 m, which hinders detail analysis.

DEM generation requires many processing steps such as camera modeling, stereo matching, editing, interpolating and so on. All these steps contribute to the quality of DEM. Among all the steps, stereo matching is crucial to the accuracy and completeness of a DEM. Stereo matching is a process of finding conjugate points in a stereo image pair. A number of publications regarding stereo matching techniques for various applications have been published.

With the strong advantage in providing high resolution of 2.5m with three independent optical systems in viewing forward, nadir and backward that provides along-track overlapping images, PRISM sensor on-board ALOS (Advanced Land Observation Satellite) is capable to provide along-track stereoscopic imagery. PRISM is a panchromatic radiometer with a wavelength of 0.52µm to 0.77µm and 2.5m spatial resolution. Its high resolution of 2.5m has a good potential for 1:25,000 scale maps.

The nadir view telescope provides a swath of 70km width while the forward and backward view telescope provide a swath of 35km. The forward and backward view telescopes are inclined by ±24° from nadir to realize a base to height ratio of one at an orbital altitude of 692km.

This paper describes DEM generation method from ALOS-PRISM stereo pair imagery and evaluates the accuracy of generated ALOS-DEM by comparing it to SRTM-DEM of 90m spatial resolution (Figure 1). The SRTM obtained elevation data on a near global scale (80%

of the land mass) to generate the most complete high resolution digital topographic database of Earth. It consists of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11day mission in February 2000. Data in a resolution of 90m at the Equator is freely provided for most of the planet. The generated DEM was used in ATCOR3 to generate the surface reflectance map using elevation data. It considers the slope and aspect images to retrieve accurate surface reflectance values over high mountain terrain.

The satellite observation signal was the sum of the surface reflectance and atmospheric reflectance. We used ATCOR3 in the image processing software to create a surface reflectance image. The reflectance measured from the satellite [reflectance at the top of atmospheric, ρ(TOA)] was subtracted by the amount given by the surface reflectance to obtain the atmospheric reflectance. And then the atmospheric reflectance was related to the particulate matters of size less than 10 micron (PM10) using the regression algorithm analysis. The PM10 map was generated using the proposed algorithm. This produced a smoother goecoded image to reduce the random noise. The generated map was colour-coded for visual interpretation.

Specific objectives of this research grant are:

- To determining attributes of terrain over Penang Island.
- To finding the features of the terrain and to estimate the slope and aspect.
- To determine the air quality from satellite images using ATCOR3 associated with the DEM data.

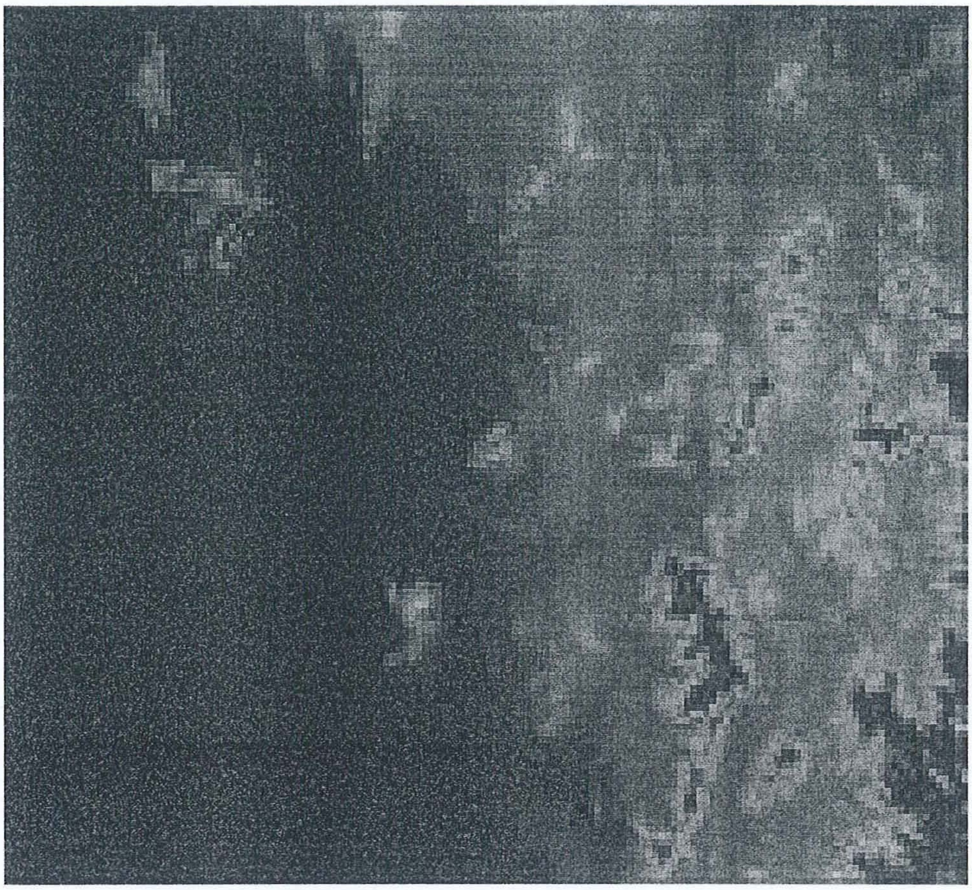


Figure 1: SRTM-DEM.

II. METHODOLOGY

In many DEM generation approaches, there is considerable user interaction. This is especially true for topographic mapping, where obtaining specified height accuracies and sufficient point distributions is very important. Such operator effort may include isolating exclusion area such as forest, building or water, and also collecting the tie points and control points. Such process may need manually operated. Another process that can require considerable operator interaction is error checking.

For all of the processing stages used, investigations will be performed and one or more possible methods will be carried out. Such processes include:

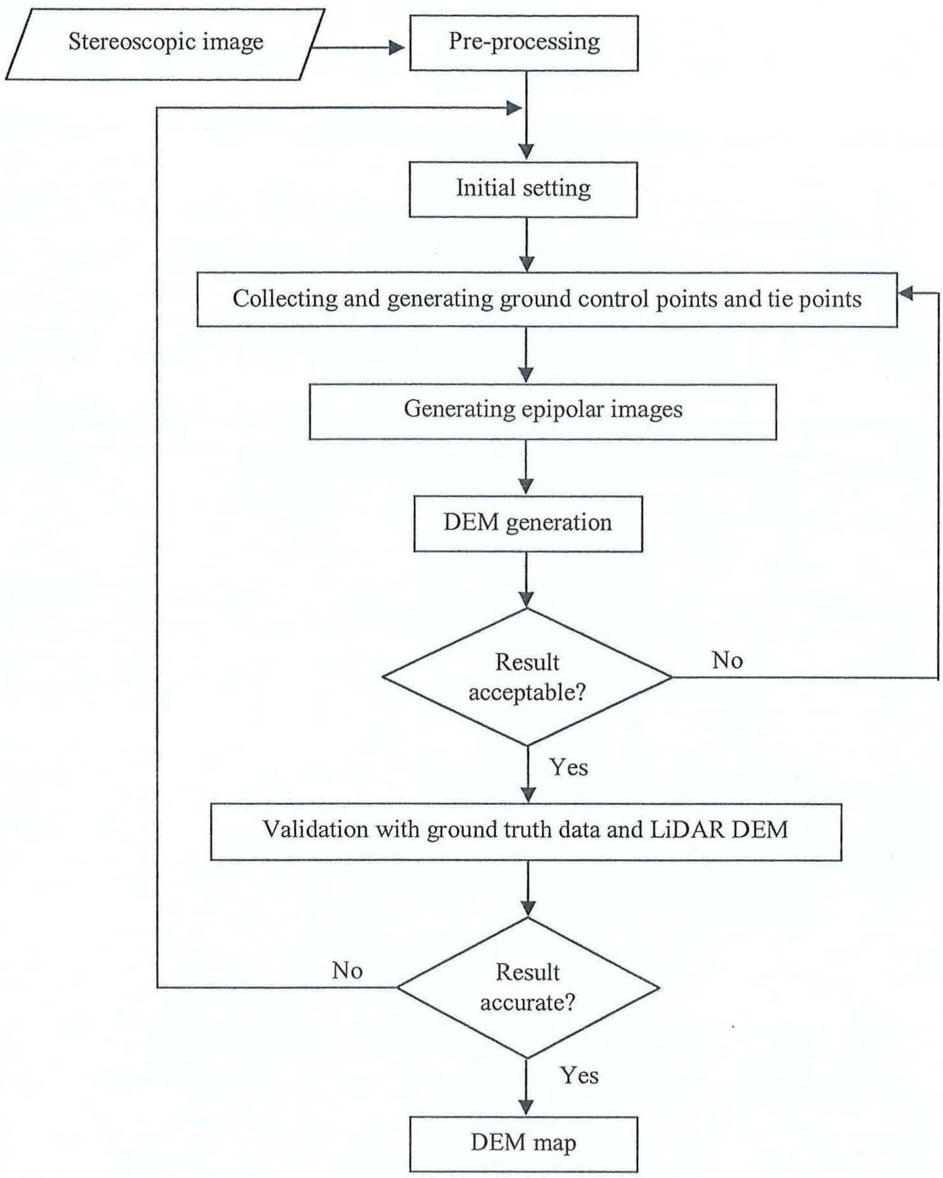
1. Pre-processing
2. GCPs / Tie points collection
3. Epipolar generation
4. DEM generation
5. Validation

The processes start with the pre-processing by extracting the stereo pair of raw PRISM imagery into the project and correct it with radiometric correction. Then, start to collect tie points and ground control points. It is essential to collect tie points because a tie point is a feature that can clearly identify in two or more images and can be selected as a reference points. It identifies how the images in the project relate to each other and compute a transformation with ground control points to improve the fit between the images when the corresponding project is using Rational Function math models which have to import Rational Polynomial Coefficient. While collecting ground control points is to derive elevation information from the stereo set. When the DEM generation process is done, the accuracy of the result will be investigated and the image matching method will be studied.

In order to validate the result, an airborne LiDAR DEM data or GPS elevation data will be used. The accuracy assessment will be done and finding the potential in correlating the airborne LiDAR DEM data and PRISM-DEM stereoscopic generated data.

The advent of high resolution sensor like ALOS-PRISM offers the opportunity to derive DEM in more detail, at least for certain kind of terrain. The participants of the project shall carry out the DEM generation.

The process flow chart is as below:



The imagery of ALOS-PRISM was used to generate the elevation. The forward-backward pair used in this paper is shown in Figure 2 and Figure 3.

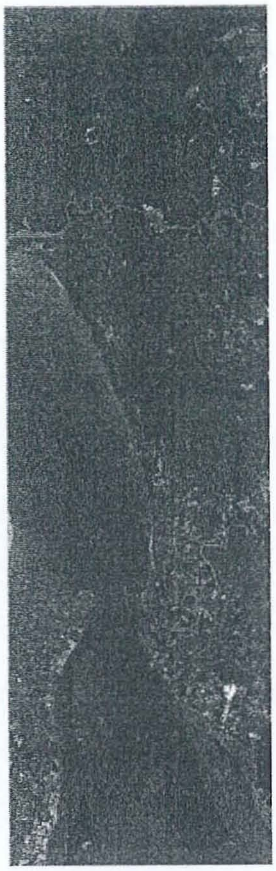


Figure 2: Forward-viewing imagery.

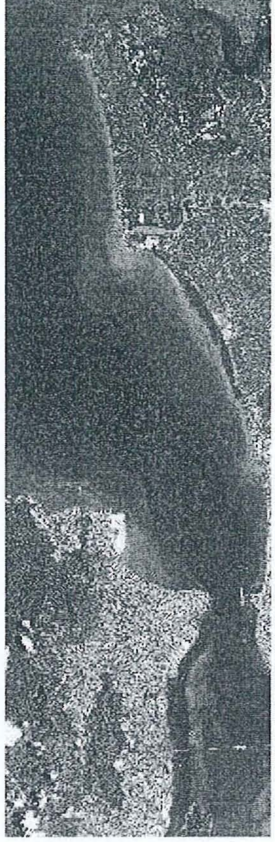


Figure 3: Backward-viewing imagery.

In DEM generation process, PCI OrthoEngine software was used. It supports the reading of different satellite data, GCP collection, geometric modeling, orthorectification, image matching, DEM generation and so on. Different correction methods are provided in the software. However, the rational polynomial function method wasis selected to be used in the processing.

During epipolar generation process forward view imagery was used as left stereo pair while the backward viewing imagery was used as right stereo pair. To define the relationship between the two stereo imageries the GCP points play important role. 10 GCP points were collected in the pair of tile imagery, with residual error of 0.49 pixels. The generated DEM is absolute in the sense that the horizontal and vertical reference systems are tied to geodetic coordinates. The generated GCPs must be checked and corrected to reduce the parallax error. The epipolar geometry was calculated and generated automatically by the software. It is important to re-project the stereo pair so that the left and right images have a common orientation, matching feature between the images appear along the x-axis. It helps to reduce the possibility of incorrect matches. The last step is generating the DEM.

After generating the PRISM-DEM, the result was then match with SRTM-DEM to find the positional accuracy. Next, a comparison between PRISM-DEM and the SRTM-DEM was made by taking 30 ground points randomly to obtain the elevation from both DEMs. The accuracy was found through plotting the correlation graph between the data of SRTM-DEM and of PRISM-DEM.

III. RESULTS AND DISCUSSION

PRISM-DEM was generated from the forward-backward viewing pair by using 10 GCPs with the residual error of 0.49 pixels. The generated PRISM-DEM is shown in Figure 4.

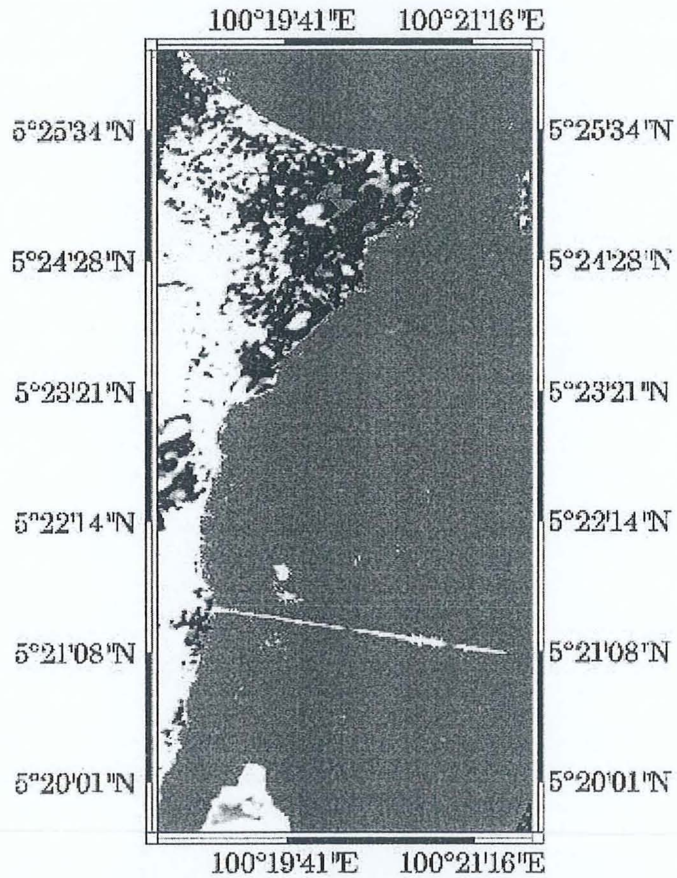


Figure 4: Generated PRISM-DEM.

Validation analysis was carried out to determine the accuracy of PRISM-DEM by comparing the elevation data to SRTM-DEM. The height distribution between PRISM-DEM and SRTM-DEM has few differences in meters.

The correlation between the two DEMs data was analyzed as well. 30 control points were collected to plot the graph with linear regression. The graph gives a correlation of R^2 = 0.8083 as shown in Figure 5 and the RMSE (root mean square error) of 0.8991meter.

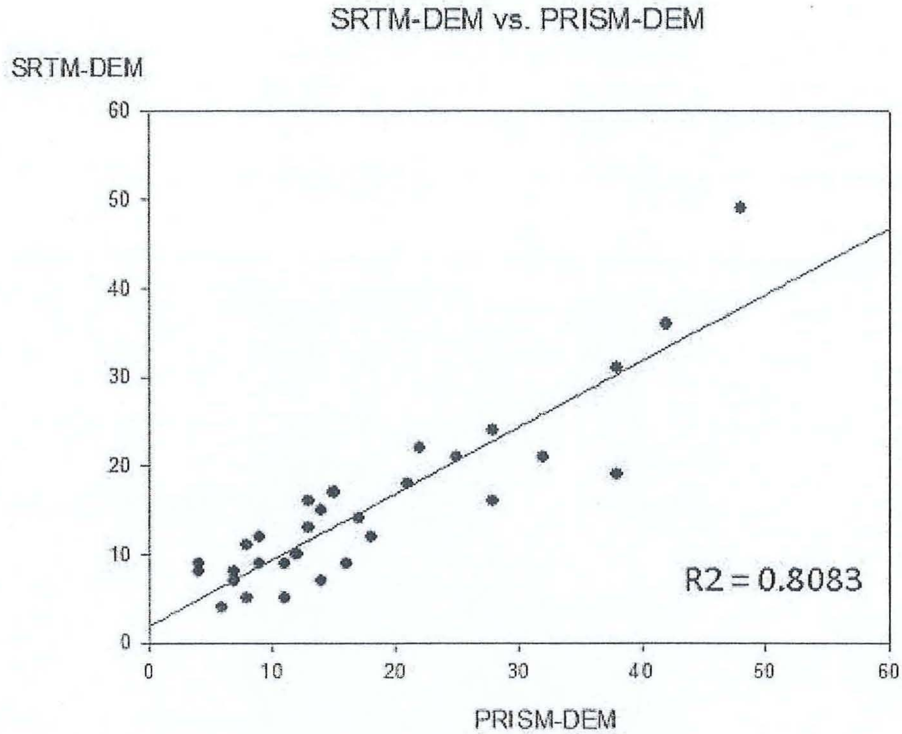


Figure 5: SRTM-DEM data vs. PRISM-DEM data.

In this study, the sea area was set to a constant value to improve the model. The sea area often gives misleading elevation values. However, the study will be continued and the problem of misleading elevation values will be studied in future.

Besides that, the generated DEM data also will be used for the ATCOR3 analysis. This is very important analysis because the quality of the DEM and the ortho-rectification has a very large influence on the radiometric processing. Atmospheric Correction (ATCOR 3) is available as an add-on to the Advanced Optical package. Variations in the earth's atmosphere and rugged terrain modify the "true" spectral characteristics of satellite imagery.

Atmospheric correction with ATCOR3 is a radiometric processing program which derives surface reflectance and temperature from satellite imagery by atmospheric and topographic correction. It eliminates atmospheric and illumination effects to ensure that you receive the most from your imagery.

In the air quality studies, the key issue in retrieving atmospheric reflectance from remotely sensed data is to identify the surface reflectance. In this study, the surface reflectance will be created using ATCOR3 associated with the accurate DEM data. The atmospheric reflectance will be obtained by subtracting the reference reflectance from the total reflectance observed by the digital images. And then the atmospheric reflectance can be related to the PM10 by using the regression algorithm analysis. Then the retrieved atmospheric reflectance values are used for regression analysis to determine the relationship between atmospheric reflectance and PM10 concentration.

Many researchers have been carried out to monitor particulates air pollution for taking actions to prevent it from becoming more serious [Ung, et al., 2003]. The problems of these particulates air quality monitoring techniques are not continuous and real time monitoring. It can be used for record purpose but not for alarming purpose to prevent any accident from happening.

A new algorithm was developed for detecting and mapping air pollution levels using the remotely sensed images. The algorithm is based on the atmospheric aerosol characteristic model and this, in turn can be related to the air pollutants concentration. The selected parameter is particulate matter less than 10 micron (PM10). In-situ measurements of corresponding air pollution parameters are carried out simultaneously with the acquisition of remotely sensed data using a DustTrack Meter 8520. Atmospheric radiation is measured using a handheld spectroradiometer. These in-situ measurements are then used as the dependent variables in deriving the air quality information using the digital camera data. The objective of this study is to test the potential of using remote sensing and image processing technique. This method is designed to detect particulates air pollution in the environment.
The atmospheric reflectance due to molecule, Rr, is given by (Liu, et al., 1996)

$$R_r = \frac{\tau_r P_r(\Theta)}{4\mu_s \mu_v} \qquad (1)$$

where
τr = Rayleigh optical thickness
Pr(Θ) = Rayleigh scattering phase function
μv = Cosine of viewing angle
μs = Cosine of solar zenith angle

We assume that the atmospheric reflectance due to particle, Ra, is also linear with the тa [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.

$$R_a = \frac{\tau_a P_a(\Theta)}{4\mu_s \mu_v} \tag{2}$$

where

тa = Aerosol optical thickness

Pa(Θ) = Aerosol scattering phase function

Atmospheric reflectance is the sum of the particle reflectance and molecule reflectance, Ratm, (Vermote, et al., (1997).

Ratm=Ra+Rr (3)

where

Ratm=atmospheric reflectance

Ra=particle reflectance

Rr=molecule reflectance

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

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

The optical depth is given by Camagni and Sandroni, (1983), as in equation (5). From the equation, we rewrite the optical depth for particle and molecule as equation (6)

$$\tau = \sigma \rho s \tag{5}$$

where

т = optical depth

σ = absorption

s = finite path

$$\tau = \tau_a + \tau_r \qquad \text{(Camagni and Sandroni, 1983)}$$

$$\tau_r = \sigma_r \rho_r s \tag{6a}$$

$$\tau_p = \sigma_p \rho_p s \tag{6b}$$

Equations (6) are substituted into equation (4). The result was extended to a three bands algorithm as equation (7) 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 PM10 was linearly related to τ and the correlation coefficient for linear was better that exponential in their study (overall). This means that reflectance was linear with PM10. In order to simplify the data processing, the air quality concentration was used in our analysis instead of using density, ρ, values.

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

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

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

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

$$P = a_0 R_{atm}(\lambda_1) + a_1 R_{atm}(\lambda_2) \tag{7}$$

where

P = Particle concentration (PM10)

G = Molecule concentration

Ratmi = Atmospheric reflectance, i = 1 and 2 are the band number

aj = algorithm coefficients, j = 0, 1, 2, ... are then empirically determined.

Landsat TM satellite data set was selected corresponding to the ground truth measurements of the pollution levels. The PCI Geomatica version 10.1 image processing software was used in all the analyses. The Landsat TM 5 satellite images were acquired on 15th February 2001 (Figure 6), 17th January 2002 (Figure 7), 6th March 2002 (Figure 8) and 5th February 2003 (Figure 9).

Raw digital satellite images usually contain geometric distortion and cannot be used directly as a map. Some sources of distortion are variation in the altitude, attitude and velocity of the sensor. Other sources are panoramic distortion, earth curvature, atmospheric refraction and relief displacement. So, to correct the images, we have to do geometric correction. After applying the correction, the digital data can then be used for other processing steps. Image rectification was performed by using a second order polynomial transformation equation. The images were geometrically corrected by using a nearest neighbour resampling technique. Sample locations were then identified on these geocoded images. Regression technique was employed to calibrate the algorithm using the satellite multispectral signals.

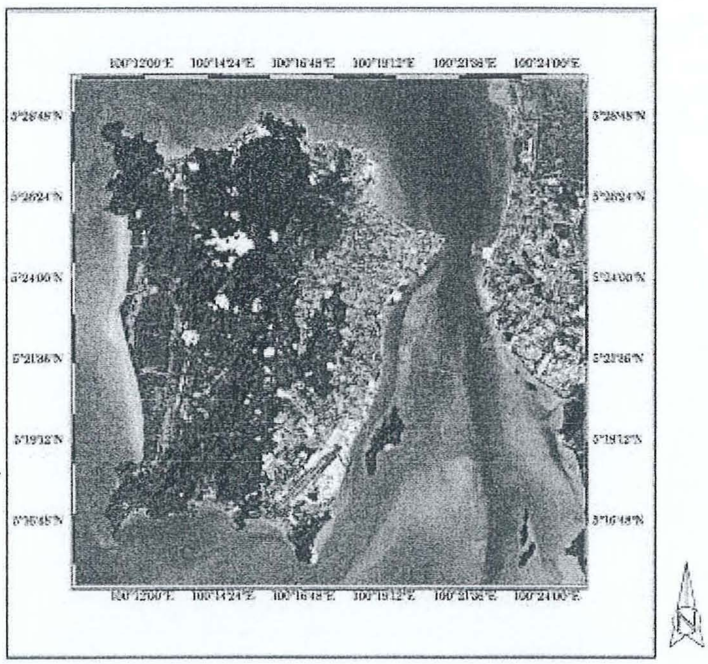


Figure 6: Raw Landsat TM satellite image of 15th February 2001.

Figure 7: Raw Landsat TM satellite image of 17th January 2002.

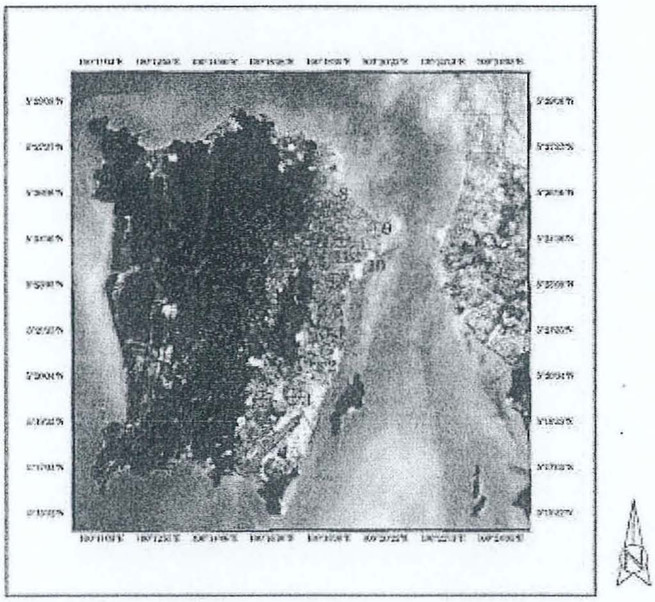


Figure 8: Raw Landsat TM satellite image of 6th March 2002.

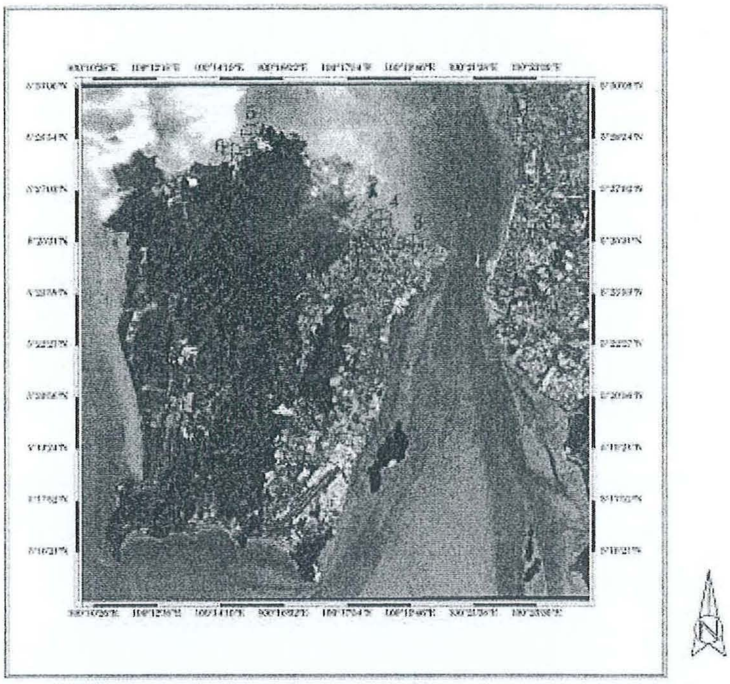


Figure 9: Raw Landsat TM satellite image of 5th February 2003.

It should be noted that the relfectance values at the top of atmosphere is the sum of the surface reflectance and atmospheric relfectance. The signals measured in each of these visible bands represent a combination of surface and atmospheric effects, usually in different proportions depending on the condition of the atmosphere. Therefore, it is required to determine the surface contribution from the total reflectance received at the sensor. The retrieval of surface reflectance is important to obtain the atmospheric reflectance in remotely sensed data and later used for algorithm calibration. An algorithm was developed based on the aerosol properties to correlate the atmospheric reflectance and PM10. In order to obtain the surface reflectance values, ATCOR3, in the PCI Geomatica version 10.1 digital image processing software was used in this study. ATCOR3 generates a surface reflectance map using elevation data. It considers the slope and aspect images to produce an accurate retrieval of surface reflectance values over high mountain terrain. ATCOR3 is useful to evaluate surface reflectance values in 3D because the digital elevation model (DEM) must be used to generate the surface reflectance map. Therefore, in this study, the reference DEM model was used to retrieve the LST. In addition, ATCOR3 also has a built-in function for atmospheric correction, which is available for visible bands Landsat data. The user must provide the input layer with specific visibility parameters to perform the atmospheric correction. The other input parameters required are the data acquisition and solar azimuth and solar zenith angles. All of these input parameters may be obtained from the header file of satellite imagery. For the visibility of satellite images obtained from Penang, Malaysia Forecast Weather Underground (http://www.wunderground.com/global/stations/48601/htm) was used. The supported sensors that retrieved surface reflectance values by ATCOR3_T are Landsat -4/5 TM (band 6), Landsat-7 ETM+ (band 6) and ASTER (band 13). In this study, a simple form of the equation was used in this study (Equation 11). This equation also used by other research in their study (Popp, 2004).

$$R_s - TR_r = R_{atm} \tag{10}$$

$$R_s - R_r = R_{atm} \tag{11}$$

where:

Rs = reflectance recorded by satellite sensor

Rr = reflectance from surface references

Ratm = reflectance from atmospheric components (aerosols and molecules)

T = transmittance

It should be noted that the relfectance values at the top of atmosphere was the sum of the surface reflectance and atmospheric relfectance. In this study, we used ATCOR2 image correction software in the PCI Geomatica 10.2 image processing software for creating a surface reflectance image. And then the reflectance measured from the satellite [reflectance at the top of atmospheric, ρ(TOA)] was subtracted by the amount given by the surface reflectance to obtain the atmospheric reflectance. And then the atmospheric reflectance was related to the PM10 using the regression algorithm analysis (Equation 7). In this study, Landsat TM signals were used as independent variables in our calibration regression analyses. The atmospheric reflectances for each band corresponding to the ground-truth locations were determined. The atmospheric reflectance were determined for each band using different window sizes, such as, 1 by 1, 3 by 3, 5 by 5, 7 by 7, 9 by 9 and 11 by 11. In this study, the atmospheric reflectance values extracted using the window size of 3 by 3 was used due to the higher correlation coefficient (R) with the ground-truth data. The extracted atmospheric reflectance values were regressed with their respective ground -truth data and the proposed algorithm to obtain the regression coefficients. PM10 maps for all the images were then generated using the proposed calibrated algorithm and filtered by using a 3 x 3 pixel smoothing filter to remove random noise.

The data points were then regressed to obtain all the coefficients of equation (7). Then the calibrated algorithm was used to estimate the PM10 concentrated values for each image. The proposed model produced the correlation coefficient of 0.8 and root-mean-square error 16 μg/m3. The PM10 maps were generated using the proposed calibrated algorithm. The generated PM10 map was colour-coded for visual interpretation [Landsat TM 5 - 15th February 2001 (Figure 10), 17th January 2002 (Figure 11), 6th March 2002 (Figure 12) and 5th February 2003 (Figure 13)]. Generally, the concentrations above industrial and urban areas were higher compared to other areas.

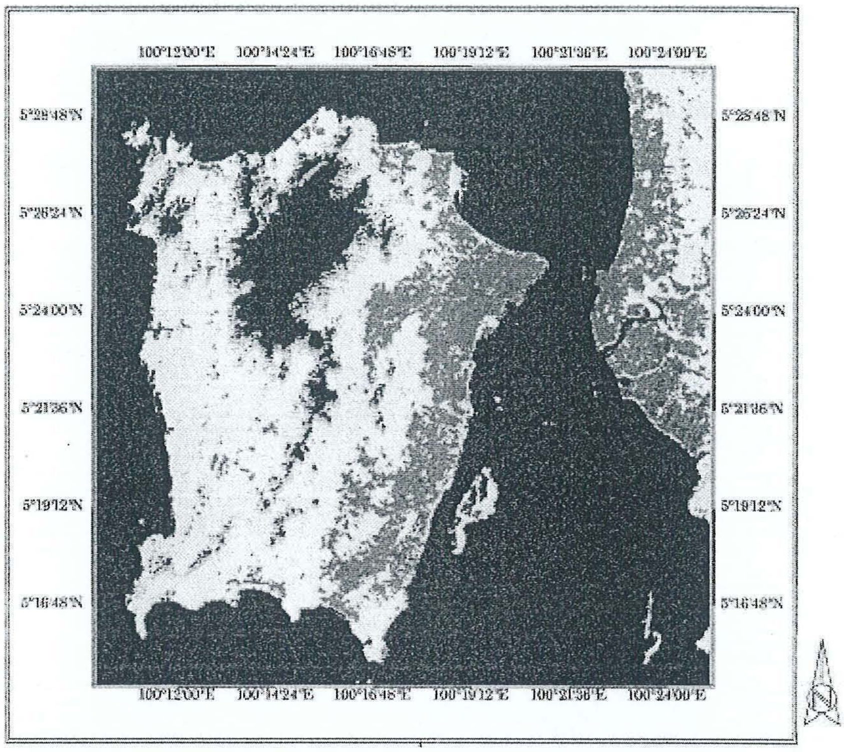


Figure 10: Map of PM10 around Penang Island, Malaysia-15/2/2001 (Blue < 40 μg/m^3, Green = (40-80) μg/m^3, Yellow = (80-120) μg/m^3, Orange = (120-160) μg/m^3, Red = (>160) μg/m^3 and Black = Water and cloud area).

Figure 11: Map of PM10 around Penang Island, Malaysia-17/1/2002 (Blue < 40 µg/m^3, Green = (40-80) µg/m^3, Yellow = (80-120) µg/m^3, Orange = (120-160) µg/m^3, Red = (>160) µg/m^3 and Black = Water and cloud area).

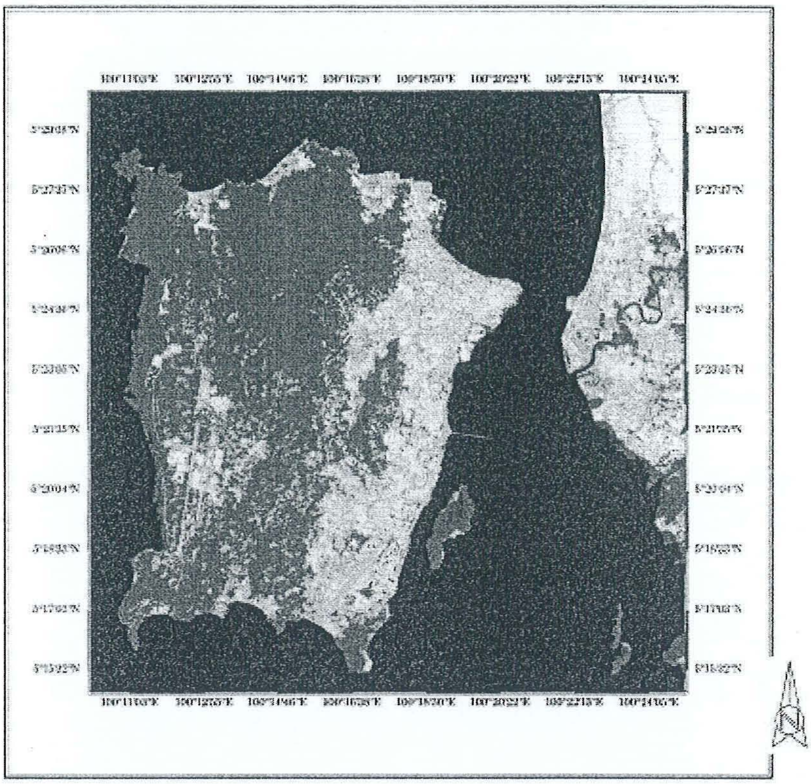


Figure 12: Map of PM10 around Penang Island, Malaysia-6/3/2002 (Blue < 40 µg/m^3, Green = (40-80) µg/m^3, Yellow = (80-120) µg/m^3, Orange = (120-160) µg/m^3, Red = (>160) µg/m^3 and Black = Water and cloud area).

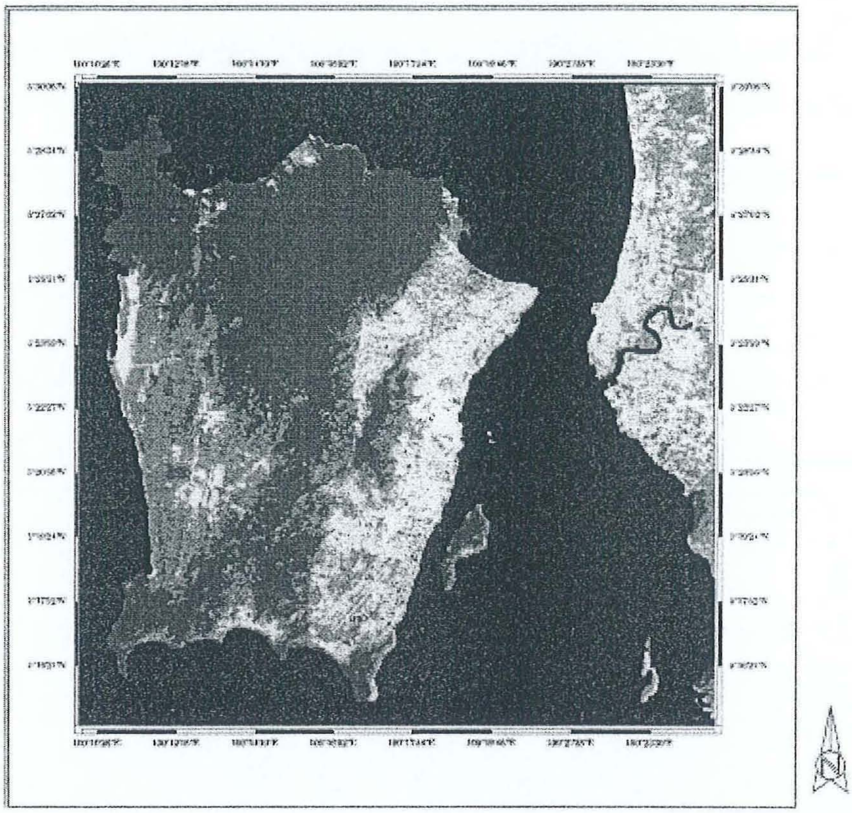


Figure 13: Map of PM10 around Penang Island, Malaysia-5/2/2003 (Blue < 40 μg/m^3, Green = (40-80) μg/m^3, Yellow = (80-120) μg/m^3, Orange = (120-160) μg/m^3, Red = (>160) μg/m^3 and Black = Water and cloud area).

IV. Conclusion

This paper describes DEM generation from forward-backward viewing stereoscopic pair of ALOS-PRISM using commercial software PCI OrthoEngine. The stereo pair data can be used to generate DEM with high spatial resolution of 2.5 meter. Visual observation result shows that it has a smooth elevation pattern. However, the sea area provides misleading elevation and it is still under research process. This study indicates that Landsat TM satellite data can provide very useful information for estimating and mapping air pollution. The proposed algorithm is considered superior based on the values of the correlation coefficient, R=0.8 and root-mean-square error, RMS=16 μg/m^3. This technique has been proved to be reliable and cost effective for such environmental study. Further study will be carried out to verify the results.

V. *GOVERNMENT AND INDUSTRIAL RELATION*

In upholding national aspiration in sculpturing universities into a dynamic knowledge center that not only able to produce high qualified graduates but also excel in its research and development, we have raises our effort in reaching to the horizon through established collaboration with various external agencies such as government institution and industries. A the very early stage of this research, we have extended our interest to collaborate with national Space Agency (ANGKAS). We will proceed with official research agreement and collaboration with ANGKASA once all the research methods and facilities are in place since currently the research is still within lab procedures in identifying air quality parameters at several location of Peninsular Malaysia. Our objective here is to be able to tackle the real issues related to air pollution in Malaysia and to utilise our funding from government of Malaysia to enhance our expertise and to deliver its benefit back to the nation.

Besides collaborating on research ground, we are also developing and promoting our training materials on experimental optics such as on the applications of spectroradiometer and PCI Geomatica software. The target participants are among government researchers and industrial (technical) personnel. We have successfully conducted 10 days training for a group of ANGKASA technical personnel on "Short Courses on Research using Spectroradiometer". In this course we have trained the participants on the application of spectrometer using ASD and JAZ (purchased using EScience Fund) spectrometer system. Besides, we have produced our own tutorial module for PCI Geomatica training on introductory basis and currently this module is distributed internally. Further effort is continuously being made in upgrading the module with the hope it can support the need among optical industries especially in Penang to upgrade their technical expertise. This effort is being made through collaboration with USAINS Group, Universiti Sains Malaysia. Currently, the training is conducted for undergraduate and postgraduate students.

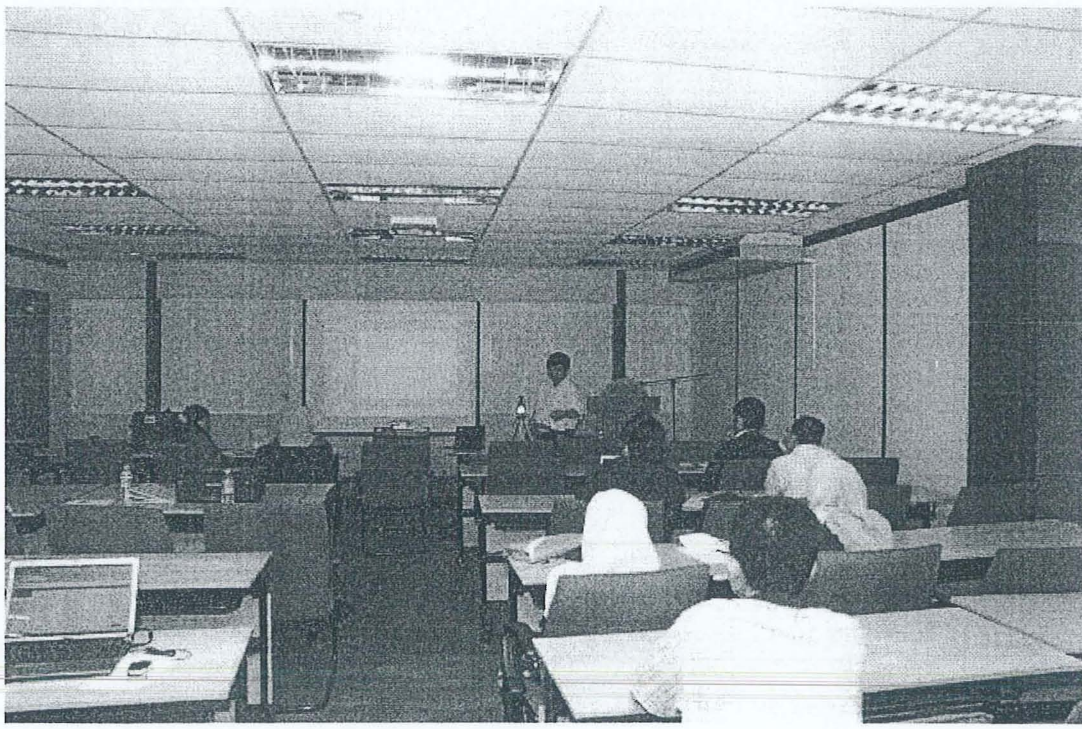


Figure 14: USM-ANGKASA Training on Spectroradiometer.

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Lampiran D

A DEM for the area of interest is necessary. The topographic effects strongly influence the recorded signal. The processing eliminates the atmospheric/topographic effects and generates surface data (reflectance, temperature) corresponding to a flat terrain. Problems can arise in regions where the spatial resolution of the DEM is not adequate. Besides that, the generated DEM data also will be used for the ATCOR3 analysis. This is very important analysis because the quality of the DEM and the ortho-rectification has a very large influence on the radiometric processing. Atmospheric Correction (ATCOR 3) is available as an add-on to the Advanced Optical package. Variations in the earth's atmosphere and rugged terrain modify the "true" spectral characteristics of satellite imagery. Atmospheric correction with ATCOR3 is a radiometric processing program which derives surface reflectance and temperature from satellite imagery by atmospheric and topographic correction. It eliminates atmospheric and illumination effects to ensure that you receive the most from your imagery.

In the air quality studies, the key issue in retrieving atmospheric reflectance from remotely sensed data is to identify the surface reflectance. In this study, the surface reflectance will be created using ATCOR3 associated with the accurate DEM data. The atmospheric reflectance will be obtained by subtracting the reference reflectance from the total reflectance observed by the digital images. And then the atmospheric reflectance can be related to the PM10 by using the regression algorithm analysis. Then the retrieved atmospheric reflectance values are used for regression analysis to determine the relationship between atmospheric reflectance and PM10 concentration.