ESTABLISHMENT OF PEREZ DU- MORTIER CALIBRATION ALGORITHM AS A SUNPHOTOMETERS CALIBRATION PROTOCOL AT ALTITUDE ABOVE SEA LEVEL

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IJAZAH: **MASTER OF SCIENCE (PHYSICS WITH ELECTRONICS)**

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DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

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ABSTRACT

Calibration of sunphotometer using Langley technique requires direct sun irradiance data during very clear and stable atmospheric condition. However, it is impenetrable to find cloud free condition at near sea level altitude especially tropical country due to cloud loading and rainfall throughout the year. Recently, near sea level Langley calibration method for ground based measurement was developed by combining Perez Du- Mortier (PDM) algorithm with statistical filter. It is already known that PDM as an improved Langley method are capable in calibrating sunphotometers at near-sea- level. Therefore, this research are focused on the implementation of PDM as establish calibration protocol at different altitudes above sea level. In order to achieved this desired, this improved Langley method should be able to achieve standard target as a establish calibration protocol by producing results that are approaching Standard Langley Method. Thus, in this research, the performance of PDM method was examined at three different altitude site where data were collected at site A for high altitude at 3,270 m a.s.l, Site B for mid altitude (1,574 m a.s.l.), and site C for low altitude (7.8 m a.s.l) for four nominal wavelengths. Calibration constant retrieved by PDM at different altitude were compared with Standard Langley Method which performed at high altitude. Result shows that the reproducibility of calibration constant using the PDM calibration method at three different altitude when compared with Standard Method is acceptable to a certain extent of not greater than ~3% at most. Therefore, it prove that, PDM is feasible in calibrating sun photometer at different altitude above sea level by producing data that approaching to Standard Langley Method at high altitude.

ABSTRAK

PEMBENTUKKAN ALGORITHMA PEREZ DU- MORTIER SEBAGAI KAEDAH PENETUUKURAN ALAT PENGUKUR CAHAYA PADA ALTITUD BERBEZA

Penentukuran sunphotometer menggunakan teknik Langley memerlukan data sinaran langsung matahari semasa keadaan atmosfera yang sangat jelas dan stabil. Walau bagaimanapun, keadaan ini adalah amat mustahil untuk diperolehi di kawasan yang berketinggian paras laut kerana kehadiran awan yang kerap dan menyebabkan sukar untuk memperolehi langit yang cerah terutamanya negara yang beriklim tropika. Baru-baru ini, kaedah penentukuran spektrometer matahari untuk pengukuran di paras laut telah dibangunkan dengan menggabungkan algoritma Perez Du- Mortier (PDM) dengan penapis statistik. Ia sudah diketahui bahawa PDM mampu membuat penentuukuran di kawasan paras laut. Maka, kajian ini memberi tumpuan kepada pelaksanaan PDM untuk menjadikannya protokol penentukuran di pelbagai ketinggian. Dalam usaha untuk mencapai hasrat ini, bacaan keputusan yang diperolehi oleh PDM haruslah menghampiri bacaan kaedah Standard Langley. Dalam kajian ini, pelaksanaan kaedah PDM telah diperiksa di tiga tapak ketinggian di mana data telah dikumpul di tapak A untuk ketinggian tinggi pada 3,270 m dari aras laut, Tapak B untuk ketinggian pertengahan (1574 m dpl), dan tapak C untuk ketinggian yang rendah (7.8 m dpl) untuk empat panjang gelombang nominal. Penentukuran berterusan diambil oleh PDM di pelbagai ketinggian dibandingkan dengan Standard Langley Kaedah yang dilakukan pada ketinggian tinggi. Keputusan menunjukkan bahawa kebolehulangan pemalar penentukuran menggunakan kaedah penentukuran PDM apabila berbanding dengan Standard Kaedah adalah boleh diterima ke tahap tertentu tidak lebih besar daripada ~ 3% paling banyak. Oleh itu, ia membuktikan bahawa, PDM boleh dilaksanakan dalam menimbang fotometer matahari di pelbagai ketinggian dengan menghasilkan data yang menghampiri kepada Standard Langley Kaedah pada ketinggian tinggi.

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LIST OF ABBREVIATIONS

AOD	Aerosol Optical Depth
COD	Cloud Optical Depth

LIST OF SYMBOLS

I_d	Diffuse irradiance
I	Global irradiance
I_{dir}	Direct irradiance
R	Earth-Sun distance
ϕ_H	Zenith angle
ε	Clearness index
NI	Nebulosity index
CR	Cloud ratio
$I_{d,cl}$	Clear sky illuminance
α	Solar altitude
m	Optical air mass
$I_{o.,\lambda}$	Extraterrestrial irradiance at the top of atmosphere
T	Total irradiance
A	Surface albedo
g	Cloud asymmetry factor
μ_0	Zenith angle
C	Clear sky irradiance
πF	Extraterrestial irradiance
$\pm$	Plus minus sign
W / m^2	Watt per meter square
$k_{oz(\lambda)}$	Ozone absorption cross section
I_λ	Direct normal irradiance at the ground at wavelength λ
$\tau_{\lambda,i}$	Total optical depth of the ith scatter or absorber
m_i	Air mass of the i-th scatter or absorber through the atmosphere
$\tau_{R,\lambda,i}$	Rayleigh scattering optical depth
$\tau_{o,i}$	Ozone optical depth
$\tau_{a,i}$	Aerosol optical depth

$\tau_{g,i}$	Gas optical depth
k_{Ray}	Rayleigh scattering coefficient
H	Altitude from sea in meter
Z	Ozone concentration
P_0	Extrapolated value

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CHAPTER 1

INTRODUCTION

1.1 Solar Radiation.

The Sun is the primary sources of energy supplies for most physical and biological processes on Earth. Solar radiation is radiant energy that travels from the Sun to Earth with speed 300, 000 km per second at a distance of 150 million kilometres. As the solar radiation enters the earth- atmosphere, it experiences three processes namely reflection, absorption and scattering. These processes occur due to the interaction of radiation with Earth's atmospheric compositions such as dust, cloud, gasses and aerosol. Noted that, energy of solar radiation is not distributed evenly over all wavelength even though solar radiation a wide range of wavelength. Figure 1.1 shows the solar radiation at the top of atmosphere and the actual radiation at sea level which has been reduced due to absorption by atmospheric gasses.

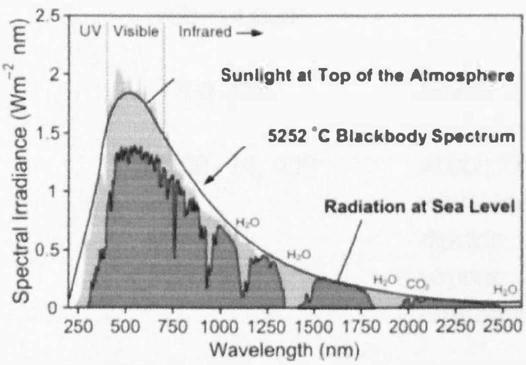

Figure 1.1 : Absorption of solar radiation by earth's atmosphere.

Source : Mohanakumar (2008)

The energy of solar radiation is sharply centred on the wavelength band of 200- 2000 nm. It can be divided into three major bands namely radiation (100- 400 0nm), visible light (400- 700 nm), and infrared radiation (700- 1000 nm). Table 1.1

presents the attenuation of solar radiation at various spectral region due to absorption of atmospheric constituents.

Table 1.1: Solar radiation and its absorption in the Earth atmosphere.

Band	Wavelength (nm)	Atmospheric effect
Gamma ray	<0.03	Completely absorbed by the upper atmosphere.
X-ray	0.03-3	Completely absorbed by the upper atmosphere.
Ultraviolet (UV)	3-400	
UV_c	200-280	Completely absorbed by oxygen, nitrogen, and ozone in the upper atmosphere.
UV_b	280-320	Mainly absorbed by ozone in the lower stratosphere.
UV_a	320-400	Transmitted through the atmosphere, but atmospheric scattering is severe.
Visible	400-700	Transmitted through the atmosphere, with moderate scattering of the shorter wave.
Infrared (IR)	700- 14,000	
Reflected IR	700-3000	Mostly reflected radiation.
Thermal IR	3, 000- 14, 000	Absorption at specific wavelengths by carbon dioxide, oxone, and water vapour, with two major atmospheric windows.

Sources : Mohanakumar (2008)

Solar radiation can be measured using either space- based or surface- based instrumentation. Instruments on satellite measure solar radiation reflected by the atmosphere, cloud and Earth surface. On the other hand, surface instruments measure the radiation incident on the Earth's surface. Surface- based instruments are often used to monitor long term atmospheric because they are able to do continuous measurement with higher temporal resolution. One of the most common examples of surface- based instrument is sunphotometers.

1.2 Sunphotometer: An Introduction, Uses and Calibration.

Ground based sun photometry contribute adequate fundamental information about the optical and physical properties of both Sun and Earth's atmosphere (McArthur *et al.,* 2013). Sunphotometers is an electronic device that measures solar irradiance over a narrow range of wavelengths and it uses light emitting diode (LEDs) as detectors (Hamasha *et al.,* 2012). Compared to past, modern sunphotometers are electronically controlled, have capability for board data storage and some of them are equipped with automated tracking system for accurate sun pointing.

Sunphotometers is commonly used on the earth's surface, as well as by aircraft for monitoring network by measuring optical properties of the atmosphere such as Cloud Optical Depth (COD) (Liu *et al.,* 2013), concentration of atmospheric gases such as O_3 and water vapour. It is also widely used for physical- optical characterization of the aerosols such as Aerosol Optical Depth (AOD) (Toledano *et al.,* 2012). Not only that, sunphotometers also have the ability to measure aerosol size distribution, and the columnar amount of water vapour, ozone and nitrogen oxide (Schmid & Wehrli, 1994).

Despite the great values of sunphotometers in many remote measurement applications, degradation of optical sensors is the most important source of the long-term changes in cross-calibrations. In other words, after long term usage, sunphotometers reading is likely to deviate and eventually resulting error in measurement. Therefore, ongoing calibration of sun photometer is necessary to account for instrument changes including changes in the sensitivity of detectors and changes in the transmittances of the interference filters.

Instrument calibration is a combination of the instrument precision, the calibration procedure, and the algorithm used (Holben *et al.,* 1998). Probably one of the best methods to calibrate sunphotometers is known as standard Langley Method (LM). It is a method for determining the top-of-atmosphere extra-terrestrial constant using ground based instrumentation across a wide range of airmass. This method eliminates the need for band pass integration, a standard lamp, or any difficulties in the absolute calibration method (Slusser *et al.,* 2000). In fact, most professional sunphotometers systems (e.g. AERONET) rely on Langley Method as their primary calibration procedure, because it can be extremely accurate, simple, versatile and most importantly freely accessible worldwide.

However, LM is restricted to stringent atmospheric conditions which usually useful only at high altitude location. One example of calibration network which actively performs sunphotometers calibration is Mauna Loa Observatories on the big island of Hawaii located at latitude 20.708 N, longitude 156.25 W and at an altitude of 3,400 meters near the summit of Mauna Loa. For other monitoring network that located far away from calibration centre, they usually calibrate their instrument by comparing the calibration value with master instrument (Xia *et al.,* 2014). Though calibration transfer is possible, the accuracy of calibration constant retrieved reduce continually especially when the transfer chain is getting longer.

Besides, not all monitoring network have same type of sun photometers plus critically not all country have their own calibration network like Mouna Loa Observatory, Hawaii. Some research institutes spend large amount of money and require long lead time for sending their instrument to overseas calibration network for calibration purpose. Therefore, to solve this problem, further study on the potential of near- sea- level- Langley Method (PDM algorithm) is taken into consideration to establish a calibration protocol above sea level for sunphotometers using PDM algorithm.

1.3 Problem Statement

As previously mentioned, standard Langley Method (LM) is common calibration protocol which have been used over the years for sunphotometers calibration at high altitude for clear sky condition and stable atmosphere. However, studies show that sites located at low and middle altitude, away from sources of pollution, can achieve sufficient stability in the atmosphere to obtain reliable calibration constant. However, it is hard to find cloud free condition at tropical country due to abundant cloud loading and rainfall throughout the year (Chang *et. al.,* 2014).