EFFECT OF WATER COLUMN ON WATER DEPTH DERIVED FROM UNMANNED AERIAL VEHICLE MULTISPECTRAL IMAGE

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DEDICATION

I dedicate my dissertation work to my family and my wife. A special feeling of gratitude to my loving parents, Ab Saman bin Abd Kader and my mother Wan Nurulhuda binti Wan Shamsuri whose words of encouragement and push for tenacity ring in my ears. My wife Ain Nur Nasuha binti Azhar and my other family members have never left my side and are very special. I also dedicate this dissertation to all my friends including my Nigerian friends Dalhatu Aliyu Sani, Babangida baiya and Danboyi Amusuk who have supported me throughout the process. I will always appreciate all they have done, especially Tam Tze Huey, Nooremi Fadzilah, Jacquoelyne Paska, Linda Roziani, Maslina Mohd Natar, Nurul amalin for helping me develop my processing skills, for the many hours of assistance for data collection, and Nurul Nadiah Yahya for assisting me and also I Net Spatial Sdn Bhd my employer. Last but not least Mr. Farid Fauzi, Mr Taufik Rosli and Mr Taufiq Razali who assited me in data collection all my Insteg's fellow.

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ABSTRACT

The term water depth refers to the depth of the water body relative to the level of the water surface. In the remote sensing approach, water depth is determined using indirect methods that retrieve the bottom level of the water body without physically touching it. In the context of satellite imaging, water depths were mapped by using two radiative transfer models, namely Depth Invariance Index (DII) and Bottom Reflectance Index (BRI). However, the estimation of water depth by using airborne and satellite-borne pose error of water column. The water depth mapping by using UAV was recently conducted through the Structure from Motion (SFM). Therefore, this study presented the effects of water column correction on the multispectral Unmanned Aerial Vehicle (UAV) image to derive water depth. The following objectives were realised, firstly to retrieve the water-leaving radiance from all target points of different depths; secondly to model the water depth by applying the radiative transfer model to water-leaving radiance and; thirdly to determine and assess the effects of the water column on depths derived from UAV image. A total of six different sets of targets which consisted of forty four different depths had been deployed at Universiti Teknologi Malaysia's swimming pool. DII and BRI radiative transfer models were used to minimise the column error on the imagery. The results showed that both radiative transfer models produced lower accuracy than direct modelling with water column correction. The best depth modelled was obtained by using log regression with band 1, which reported an accuracy of 0.042m, compared to the images corrected with BRI and DII with 0.162m and 0.128m, respectively. In conclusion, the outcomes of this study should serve as a basis for enhancing water column effect on depth estimation by using UAV multispectral image, hence, proof beneficial to assist the application of data in coastal monitoring.

ABSTRAK

Istilah kedalaman air merujuk kepada kedalaman jasad air berbanding dengan aras permukaan air. Dalam pendekatan penderiaan jauh, kedalaman air ditentukan menggunakan kaedah tidak langsung yang mengambil semula aras bawah jasad air tanpa menyentuhnya secara fizikal. Dalam konteks pengimejan satelit, kedalaman air dipetakan dengan menggunakan dua model pemindahan sinaran, iaitu Indeks Kedalaman Ketidakboleh-ubahan (DII) dan Indeks Kepantulan Bawah (BRI). Walau bagaimanapun, anggaran kedalaman air yang menggunakan angkutan-udara dan angkutan-satelit memberi keralatan ruangan air. Pemetaan kedalaman air menggunakan Pesawat Udara Tanpa Pemandu (UAV) baru-baru ini dijalankan melalui Pengstrukturan Dari Pergerakan (SFM). Oleh itu, kajian ini membincangkan kesan pembetulan ruang air pada imej kepelbagaian spektrum UAV untuk memperoleh kedalaman air. Objektif berikut adalah diamati, pertama untuk memperoleh sinaran pelepasan air dari semua titik sasaran dengan kedalaman yang berbeza; kedua untuk memodelkan kedalaman air dengan mengaplikasi model pemindahan sinaran kepada sinaran pelepasan air; dan yang ketiga untuk menentukan dan menilai kesan ruang air terhadap kedalaman yang diperoleh daripada imej UAV. Sejumlah enam set sasaran yang berbeza yang terdiri daripada empat puluh empat kedalaman berbeza telah digunakan di kolam renang Universiti Teknologi Malaysia. DII dan BRI digunakan untuk meminimurnkan ralat ruang pengimejan. Keputusan kajian 1m menunjukkan bahawa kedua-dua model pemindahan sinaran menghasilkan ketepatan yang lebih rendah daripada permodelan kedalaman terus tanpa koreksi kolum air. Model kedalaman terbaik diperoleh dengan menggunakan regresi log untuk jalur 1, dengan ketepatan 0.042m, berbanding imej yang dibetulkan dengan BRI dan DII dengan ketepatan masing-masing 0.162m dan 0.128m. Kesimpulannya, hasil kajian ini akan dijadikan sebagai asas untuk meningkatkan kesan ruang air pada anggaran kedalaman dengan menggunakan imej kepelbagaian spektrum UAV, oleh itu, bermanfaat untuk membantu aplikasi data dalam pengawasan perairan pantai.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
BRI	-	Bottom Reflectance Index
DEM	-	Digital Elevation Model
DII	-	Depth Invariant Index
FRM	-	Fiduciary Reference Measurements
GCP	-	Ground Control Points
GPS	-	Global Positioning System
GWR	-	Geographically weighted Regression
IHO	-	International Hydrographic Organization
JHJY	-	Johor Jaya
KUKP	-	Kukup
MLR	-	Multiple Linear Regression
OBIA	-	Object Based Image Analysis
OBRA	-	Optimal Band Ratio Analysis
PCA	-	Principal Component Analysis
RMSE	-	Root Mean Square Error
RS	-	Remote Sensing
RTK	-	Real Time Kinematic
SDG	-	Sustainable Development Goal
SFM	-	Structure From Motion
SPRG	-	Artificial Neural Network
UAV	-	Unmanned Aerial Vehicle
UDB	-	UAV- Derived Bathymetry
UTM	-	Universiti Teknologi Malaysia

LIST OF SYMBOLS

Δ	-	Delta
K	-	Radial Distortion
C_x	-	Principal point x
C_y	-	Principal point y
Val	-	Validation point
$\emptyset'_s$	-	Sun Zenith angle
$\emptyset'_s$	-	UAV Zenith angle
g	-	Geometric Factor
K_i	-	Attenuation Coefficient

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Water depth provides many useful information in order to do monitoring, planning and conservation of the coastal. It can also be derived by using remote sensing method. Jagalingam *et al.*, (2015) map water depth using Landsat 8 satellite imagery by applying ratio transform algorithm which shows good correlation between hydrographic chart sound value and algorithm derived. Shah *et al.*, (2020) mention that there are three methods in optical remote sensing that can be used to estimate the water depth. Emprical bathymetry methods, band ratio bathymetry method and lastly inversion bathymetry models. Those three methods have their own strength and weakness. Empirical bathymetry usually measure relations between water depth and pixel intensity. The presumption behind these band ratio bathymetric methods is that the proportion of a substrate reflectance for a couple of wavelengths is equivalent for each different substrate type within a scene.

The specific challenges associated with remote sensing of submerged ecosystem is that the water column overlaying the substrate affects the remotely sensed signal substantially because of optical attenuation of light in water (Vahtmäe, et al., 2020). Water depth, tidal variability, water quality, surface roughness of numerous substrata, as well as slope and aspect variation of benthic topography (cause diffuse reflectance effects and shading), combine to limit the accuracy with remote sensing can be applied to find substrate type. Also, application of remote sensing to monitor an aquatic ecosystem is problematic by understanding that 90% of the contribution to the signal at the top of the atmosphere in the visible depends on atmospheric and water surface characteristics (Kuhn *et al.*, 2019).

There are many researchers who had tried to correct the water column error. Budhiman *et al.*, (2012) correct the water column error by using Lyzenga, (1981) algorithm, Depth Invariance Index (DII) on Landsat ETM+ to classify the benthic habitat. Misbari and Hashim, (2016) applied the water column correction on the multi-temporal satellite imaging uses advanced sensors to monitor seagrass biomass and clarify waters that are clear to turbid. Seagrass data was culled from several seasonal multi-temporal satellite datasets. In order to map substrate cover type, Pahlevan *et al.*, (2006) also utilize DII to correct the water column error. In addition, wide application of water column correction does not end only in benthic habitat mapping, it was also used on bathymetry application. Manessa *et al.*, (2017) utilized the lyzenga's algorithm to reduce the effect of water column in deriving water depth information.

However, there are still lacks in the application of water column correction of multispectral UAV to map water depth. Rossi *et al.*, (2020) did comparison of water depth retrieval by using three methods, Satellite derived bathymetry, UAV Derived bathymetry and field data collection of echo sounder. The finding from Rossi *et al.*, (2020) state that the accuracy of the water depth estimation was having accuracy of 20 cm for depth of 5meters and deeper.

1.2 Problem Statement

Water column pose errors in deriving water depth information. The errors are crucially needed to be corrected in order to have good results in coastal applications such as water depth mapping. This is because the water bodies' bottom depths are heavily affected by the refraction of the optical rays. Refraction acts on these remotely sensed images similar to the radial distortion, differing practically at each pixel of every image, leading to unstable solutions and erroneous depths. Water depth information is helpful for many applications, including navigations, mapping and also coastal management. With the recent advancement of UAV technology, higher temporal and spatial resolution of data leads to better coastal area management.

The understanding on how water column errors affect the water depth estimation is very crucial. Previous researches had developed water column correction model such as Depth Invariance Index (DII) and Bottom Reflectance Index (BRI) especially for satellite data to tackle the issues. The model were applied in various water types across coastal and lake. The researchers showed improvement in the accuracy of water depth estimation by applying the water column correction to the satellite image. Due to high altitude of satellite data, the interference of atmospheric reduces the capabilities of the model to eliminate the water column errors. However, the application in UAV reduced the effect of the atmospheric errors and left yet the water column error.

The application of UAV for water depth retrieval by using multispectral affected by the water column error must be corrected for different water depth and types.Water type refers to category of seawater clarity, namely water type IA, II, and III for clear open ocean waters, mild turbid seawater, and turbid coastal waters, respectively. This water types is also known as Jerlov water types. Therefore, this research used the capability of Unmanned Aerial Vehicle (UAV) and multispectral image to quantify the water depth and the application of water column correction for shallow water area.

1.3 Research Questions

a) How can the water-leaving radiance be obtained by using UAV for different water depth?

b) To what extent can the radioactive transfer model using BRI and DII be minimized

c) What is the effect of water column towards depth?

1.4 Research Aim and Objectives

The main focus of this thesis is to determine the water depth from UAV image and to investigate the effect of water column to the determined depths The objectives of the research are:

a) To retrieve the water leaving radiance from all target points of different depths;

b) To model the water depth by applying the radiative transfer model to water leaving radiance; and

c) To determine and assess the effects of water column on depths derived from UAV image.

1.5 Scope of the Study

Water-leaving radiance referred to the radiance that transmitted out from the water. Water leaving radiance carries information on the water column and bottom reflectance. The area of study will only be 1m depth of swimming pool UTM. The water leaving radiance was obtained by using UAV for this study. This research uses five different types of models to calculate the water depth. The first model calculates the water depth without considering the water column. Since there is an impact of the water column in the orthophoto, this model was supposed to have low Z prediction accuracy. The depth is calculated using the relationship between spectroradiometer readings and depth in the following model. Furthermore, the depth was calculated using a Digital Elevation Model (DEM) created with Agisoft Metshape software.

In addition, empirical models were used in order to determine the relationship of each models and used for modelling purpose. To asses the accuracy of the model, Root Mean Square Error (RMSE) was conducted along with bias analysis.

Finally, the water depths were calculated using two water column correction models that included: DII and BRI. The DII water column correction was chosen in this study because it is frequently used by researchers and is well-known for its ability to correct water column errors, particularly in shallow and clear water. Whereas the BRI was adopted as it is the latest and famous especially in mapping water depths and is better suited for use in Jerlov's water type II or less cleared the water. Both models were used for the purpose of comparison

1.6 Significance of Research

Once the knowledge on this model reacts to water column errors can be understand, lower cost of water depth derived can be map in shallow area which can reduce the cost compared to the conventional bathymetry mapping with medium accuracy. Therefore, the information derived can be employed in reporting water column correction techniques and can be applied in a larger coastal environment. By understanding the effect of the water column on water depth derived from unmanned aerial vehicle, researchers and local municipality who are involve in coral and seagrass study can obtain sufficient accuracy water depth information which is crucial in mapping those features.

1.7 Study Area

The study was conducted at Universiti Teknologi Malaysia's swimming pool in Johor. Since this study would like to study on water depths, controlled environment was set up in the pool. The pool selected in this study was 1 meter depth of pool with the area of 1140 m^2. From this 1 meter pool, various depths had been introduced by using different height of target then submerged them into the pool to provide different water depth reading from the UAV.

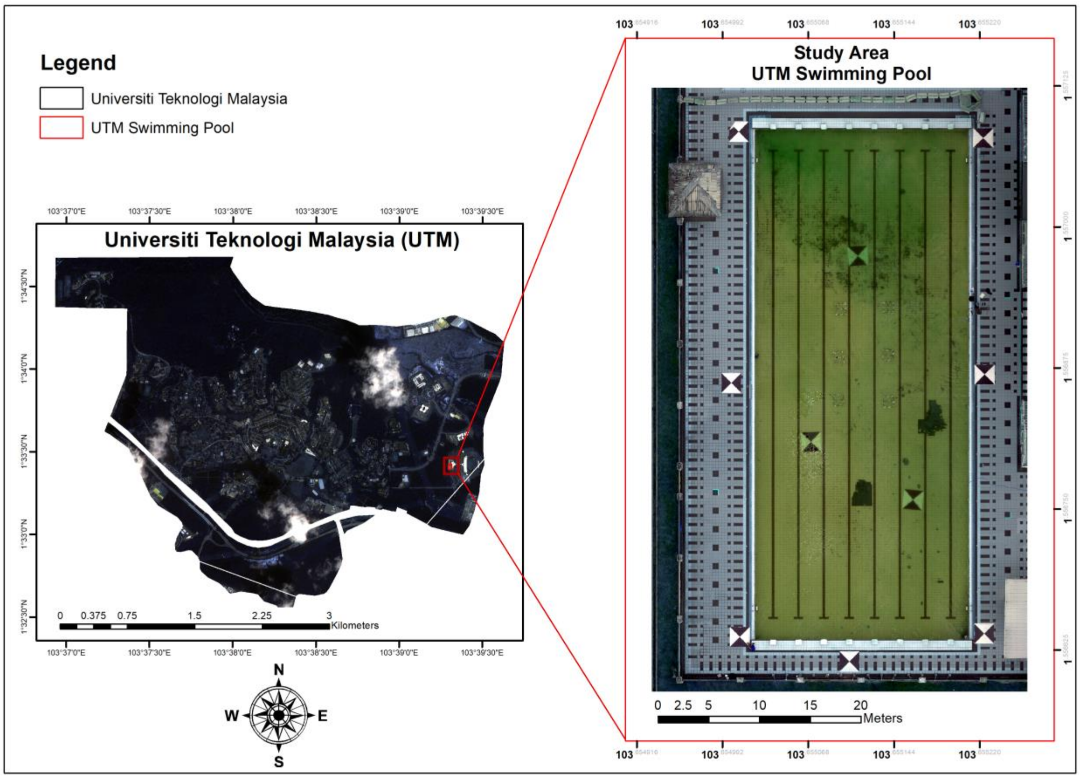

Figure 1.1 The location of Controlled Experiment

1.8 Thesis Outline

This thesis is divided into five chapters. This part discussed the summary of each chapter; Chapter One (Introduction), Chapter Two (literature Review), Chapter Three (Research Methodology), Chapter Four (Result and Analysis) and Chapter Five (Conclusion and Recommendations).

i. Chapter 1 (Introduction)

This chapter focuses on the background study, aim and objectives of this research. Besides that, this chapter also elaborated on the scope of the study in terms of study area, data that had been utilized and also the significance of the study.

ii. Chapter 2 (Literature Review)

This chapter was arranged so that it will answer each of the objectives set in chapter 1 to achieve the aim of the study. Firstly, it starts with fundamental of light and signal interacts with marines. In addition, the literature regarding method to acquire water-leaving radiance for different platforms. The chapter continues with the remote sensing model to retrieve water depth. Lastly, the techniques available in reducing water column error.

iii. Chapter 3 (Research Methodology)

This chapter describes the overall process adopted in this study to achieve objectives established. This chapter was also arranged to answer each of the objectives from first objective to third objective respectively. The explanation of the data sources and material which includes platform utilized to acquire the data, the sensor used during the data collection. Besides that, technique used on flying the drone and also the methods involve in producing the orthophoto. Moreover, the modeling technique and also the water column correction applied in this research. Lastly, the technique adopted during the assessment of the water column effect on UAV image with respect to depth.

iv. Chapter 4 (Result and Analysis)

This chapter mainly discussed on the result obtained and the analysis of the results. First section of the results shows the water leaving radiance obtained which is the orthophoto image produced itself. Next, the retrieval of water depth through five different methods namely, image without water column correction, image with DII water column correction, image with BRI water column correction, Digital Elevation Model depth's and lastly depth by the spectroradiometer readings. The assessment and discussion of the models also had been done in this chapter.

v. Chapter 5 (Conclusion and Recommendation)

This chapter comprise the conclusion and future recommendation works of the study.

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