AN OPTIMIZED VOLUME DETERMINATION METHOD BASED ON AERIAL PHOTOGRAMMETRY APPROACH FOR SUSTAINABLE ENVIRONMENT

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DEDICATION

Praise be to God The Almighty, with His blessing and mercy upon me, and His Beloved Prophet Mursyidul Kamil SAW. I could finish this thesis with His permission and berkah of Prophet SAW. This thesis is dedicated to my beloved parents (Mek Mas Hamid and Yusoff Noor), beloved wife (Farah Ahmad Lutfi), beloved children (Uwaiys El Ameen and Ahmad Luqman El Hakeem), and beloved family and family in law, who pray for my success in world and hereafter.

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ABSTRACT

Beach erosion occurs continuously along the shoreline due to the interaction of natural processes. The beach volume aspect is critical to represent the entire profile of beach evolution. Most advanced survey techniques are costly, requiring arduous control survey setup effort to measure the beach volume. Unmanned Aerial Vehicle (UAV) systems have recently attracted interest in the mapping community, which provides similar products to aircraft systems and comes with Structure from Motion – Multi View Stereo (SfM-MVS) technology at a lower cost. The UAV photogrammetric beach volume mappings were mostly conducted by using non-optimal methods such as low altitude mapping, bundle amount of Ground Control Points (GCPs) distribution, and uncalibrated Ground Sample Distance (GSD). Hence, this study aims to invent an optimized volume determination method accurately using Unmanned Aerial Vehicle (UAV) photogrammetry mapping to minimize work time and perform less laborious beach mapping work for sustainable environment study through several objevtives, firstly, to investigate the camera calibrations, UAV altitudes, and GCPs distribution for optimized beach volume UAV mapping method, secondly, to modify the SfM-MVS photogrammetric volume formula for the development of accurate and optimized beach volume mapping method, and thirdly, to analyze the optimized beach volume mapping method produced. The study was conducted at Desaru Beach, Universiti Teknologi Malaysia (UTM), Irama Beach 1, and Irama Beach 2. Various GCP distributions (3, 4, 5, 6, 8, 10, 15, and 20 GCPs) and UAV mapping altitude differences at 10m, 20m, 30m, 40m, 50m, 60m, 80m, and 100m were studied. This study utilized robust statistical analysis to investigate the beach volume measurement trend and UAV mapping behaviour from various GCP distributions and different UAV altitude mapping. The study results indicated that 4GCP and 100m altitude UAV mapping were the optimal methods for measuring beach volume using UAV with minimal mapping work. Based on the modified photogrammetric volume calculation methods in determining the beach volume, it is evident that the beach volume value is significant. In conclusion, this study shows that the modified photogrammetric volume formula provides better accuracy than the existing volume formula.

ABSTRAK

Hakisan pantai berlaku secara berterusan di sepanjang garis pantai adalah disebabkan oleh interaksi proses alam semula jadi. Aspek isipadu pantai penting bagi mewakili keseluruhan perubahan profil pantai dalam kajian pemuliharaan persekitaran. Sebahagian besar kaedah pengukuran yang canggih adalah mahal, memerlukan usaha yang sukar dalam penyediaan ukur kawalan bagi mengukur isipadu pantai dengan tepat. Sistem Pesawat Udara Tanpa Pemandu (UAV) baru- baru ini menarik minat dalam komuniti pemetaan, yang menyediakan produk yang hampir sama dengan sistem pesawat udara dan disertakan dengan teknologi Struktur daripada Gerakan – Stereo Berbilang Pandangan (SfM-MVS) pada kos yang lebih rendah. Pemetaan pantai UAV fotogrametri ini kebanyakannya menggunakan kaedah yang tidak optimum seperti pemetaan ketinggian rendah, jumlah pengagihan Titik Kawalan Bumi (GCP) yang banyak, dan Jarak Sampel Tanah (GSD) yang tidak dikalibrasi. Oleh itu, tujuan kajian ini adalah untuk mencipta kaedah penentuan isipadu yang optimum secara tepat mengunakan pemetaan UAV bagi mengurangkan waktu bekerja dan melakukan kerja pengukuran pantai yang kurang sukar bagi kajian persekitaran yang mampan melalui beberapa objektif, pertama, untuk mengkaji kalibrasi kamera, ketinggian UAV, dan taburan GCP bagi kaedah pemetaan pantai UAV yang optimum, kedua untuk mengubah suai rumus isipadu SfM-MVS fotogrametri bagi pembangunan pengukuran kaedah pemetaan isipadu pantai yang optimum dan tepat, dan ketiga, untuk menganalisis kaedah pengukuran optimum isipadu pantai yang dihasilkan. Kajian ini dilakukan di Pantai Desaru, dataran Universiti Teknologi Malaysia (UTM), Pantai Irama 1, dan Pantai Irama 2. Pelbagai taburan GCP (3, 4, 5, 6, 8, 10, 15, dan 20 GCP) dan perbezaan ketinggian pemetaan UAV pada 10m, 20m, 30m, 40m, 50m, 60m, 80m, dan 100m telah dikaji. Kajian ini menggunakan analisis statistik yang kukuh bagi menyelidik perubahan pengukuran isipadu pantai dan perubahan pemetaan UAV daripada pelbagai taburan GCP dan perbezaan tinggi penerbangan UAV. Keputusan kajian menunjukkan bahawa 4GCP dan 100m ketinggian pemetaan UAV adalah kaedah pengukuran optimum untuk mengukur isipadu pantai menggunakan UAV dengan penggunaan kerja pengukuran yang minimum. Berdasarkan kaedah pengiraan isipadu fotogrametrik yang diubah suai dalam menentukan isipadu pantai, ternyata nilai isipadu pantai adalah signifikan. Kesimpulannya, kajian ini menunjukkan bahawa formula isipadu fotogrametri yang diubah suai memberikan ketepatan yang lebih baik daripada formula isipadu sedia ada.

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LIST OF ABBREVIATIONS

UAV	-	Unmanned Aerial Vehicle
LiDAR	-	Light Detaction and Range
PLS	-	Permanent Laser Scanner
GNSS	-	Global Navigation Satellite System
TLS	-	Terrestrial Laser Scanner
MLS	-	Mobile Laser Scanner
DEM	-	Digital Elevation Model
SfM-MVS	-	Stracture from Motion –Multi View Strereo
SfM	-	Stracture from Motion
GCPs	-	Ground Control Points
UTM	-	Universiti Teknologi Malaysia
TBC	-	Trimble Business Centre
DSM	-	Digital Surface Model
USA	-	United State of America
GPS	-	Global Positioning System
USGS	-	United State Geological Survey
EPR	-	End Point Rate
LRR	-	Linear Regression Rate
AOR	-	Average of Rates
WLR	-	Weighted Linear Regression
GIS	-	Geospatial Information System
3D	-	3-Dimensional
VTOL	-	vertical take-off and landing
MAV	-	Micro UAV
NAV	-	Nano-Air Vehicles
RPH	-	Remotely piloted helicopter
MUAV	-	Mini UAV
HALE	-	High-altitude long-endurance
MALE	-	Medium-altitude long-endurance
TUAV	-	Medium-Range or Tactical UAV

HD	-	High-Defination
ISO	-	International Organization for Standardization
M	-	Megapixel
GLONASS	-	Global Navigation Satellite System
RTK	-	Real Time Kinematic
VRS	-	Virtual Reference Station
H_O	-	Null hypothesis
H_A	-	Alternative hypothesis
ANOVA	-	Analysis of Variance
m	-	Meter
cm	-	Centimeter
mm	-	Milimeter
m^3	-	Meter cubic
m^2	-	Meter square

LIST OF SYMBOLS

$E^2{}_s$	-	Seasonal error
$E^2{}_s$	-	Tidal fluctuation
$E^2{}_d$	-	Digitizing error
$E^2{}_r$	-	Rectification error
$E^2{}_p$	-	Pixel error
E	-	Shoreline uncertainty value
C	-	Calibrated focal length
W	-	Format size
Y	-	Format size
Xp	-	X Principle point
Yp	-	Y Principle point
K1	-	Radial lens distortion Parameter
K2	-	Radial lens distortion Parameter
K3	-	Radial lens distortion Parameter
P1	-	Decentering lens distortion Parameter
P2	-	Decentering lens distortion Parameter
B1	-	Affinity Parameter
B2	-	Affinity Parameter
Vi	-	Volume
Li	-	Length of the cell.
Wi	-	Width of the cell.
Hi	-	Height of the cell.
ZTi	-	Altitude of each cell at the cell center
ZBi	-	Base altitude of each cell at the cell center
GSD	-	Ground Sample Data
V_i	-	Existing photogrammetric volume
PS	-	Pixel size
h_{UAV}	-	UAV altitude
f	-	Focal length

V_O	-	Optimized photogrammetric volume
V_P	-	PiX4D volume
GSD_P	-	Ground Sample Distance Pix4D Project
A_P	-	PiX4D area
H_{ip}	-	Overall PiX4D cells height
a x b	-	Area dimension
μ	-	Mean
α	-	Alpha

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Volume determination method using photogrammetry approach is one of the advanced technology in survey and mapping study. The embedded Structure from Motion – Multi View Stereo (SfM-MVS) technology in photogrammetry give the mapping applications possible for the volume determination (Nagendran & Mohamad Ismail, 2020).

Nowadays, aerial photogrammetry mapping can be performed anywhere with the close-range method. The presence of Unmanned Aerial Vehicle (UAV) technology gives aerial photogrammetry mapping more possible to handle inaccessible landform mapping such as the extremely eroded beach. Apart from that, the natural protection dealing with volume determination on the beach evolution monitoring for the eroded beach is important for sustainable environment research. One of the sustainable environment research is about the beach evolution prediction model studies with volume parameter as an essential parameter in dealing with natural beach protection propose, which have been studied by Nielsen and Hanslow (1991); Ruggiero et al. (2001); Stockdon, H.F. et al. (2006); and Mather et al. (2011). Hence, the important of the volume determination for sustainable environment research in beach evolution is important for the future beach protection and beach monitoring, especially on the beach erosion impact.

It is believed that beach erosion occurs continuously along the coastline due to interactions of mother nature processes like sea currents, heavy winds, tides change, extreme storms, and also because of humans (Natesan et al., 2015). One of the prominent effects of beach erosion was due to the extreme storm, which leads to overwash, inundation, and erosion that affect the beach property, facilities, and loss of human life (Ferreira et al., 2018). Some part of the worlds experienced extreme storms such as the Hercules Storm in England and France (Masselink et al., 2016; Castelle et al., 2015), Xynthia Storm (Burvingt et al., 2017); the Superstorm Sandy in the USA and Caribbean (Bennington and Farmer, 2015; Clay, 2016), Hurricane Katrina Storm in the USA (Link, 2010; Kantha, 2013), and Haiyan Typhoon in the Philippines.

In addition, some beach damages happened due to climate change and sea-level rise, which is predicted to impact the beach area, but it also happens because of human activities and coastal development (IPCC, 2014; Neumann et al., 2015). Beach erosion is also one of the common catastrophic phenomena happen among countries that have the coastal area, including Malaysia (Mohd Fazly, Maulud, Karim, Ibrahim, Benson and Wahab, 2018). **Malaysia's coastline area covers about 4,809 km, and 1,300 km of** Malaysian beaches are experiencing coastal erosion impact (Ong, 2001).

Due to nature and humans' activities that contributed to the beach erosion phenomena, national authorities and many studies researched to monitor, predict and investigate the beach evolution erosion activities along the coastline (Davidson et al., 2017). Among the studies, the coastal change studies are categorized as coastline changes, and beach volume changes (Yusoff et al., 2019). The authorities and many studies recently used to investigate the beach evolution using geospatial survey sensors implementation. Various types of geospatial survey sensors have been used to monitor the beach area, as well as beach volume measurement mapping like Unmanned Aerial Vehicle (UAV) (Ma et al., 2016; Yoshinao Matsuba, 2017; Uto et al., 2017; Yoo and Oh, 2016; Drummond et al., 2015; Turner et al., 2016; Kim et al., 2017; Papakonstantinou et al., 2016; Scarelli et al., 2017; Long et al., 2016; Suganuma et al., 2017; Gonçalves and Henriques, 2015). Advanced geospatial sensors also one of the fewer used-sensors for a coastal survey and monitoring studies, such as Mobile LiDAR studied by Bitenc et al. (2011), bathymetry survey echo sounder technology such as Marinho et al. (2018), Permanent Laser Scanner (PLS) such as Vos et al. (2017), Terrestrial LiDAR such as Corbí et al. (2018) and Michael (2014), and UAV LiDAR such as Assenbaum (2018).

The importance of beach volume measurement makes many advanced geospatial technologies are used to measure and calculate the beach volume for beach sustainable environment research. Most advanced survey techniques are expensive to implement such as LiDAR mapping, and some geospatial technology sensors have a problem measuring the beach volume accurately. It is because the eroded beach landform is inaccessible to be reached by many sensors. It also contributes to laborious work for control surveys along the beach area as difficulties happen for UAV photogrammetry (Ierodiaconou et al., 2016).

Therefore, the beach volume measurement using UAV photogrammetric technology is a significant study as it enables accurate mapping results with time-efficient without wasting laborious work. Hence, the fundamental research study is organized in this thesis focusing on optimizing the UAV mapping method for beach volume measurement and modifying the SfM-MVS photogrammetric volume formula for sustainable environment monitoring study.

1.2 Problem Statement

The volume measurement is crucial for the measurement of excavation land survey areas like mining places as studied by Nagendran and Mohamad Ismail, (2020). Subsequently, the volume measurement for sandy beach volume changes monitoring is necessary for beach monitoring and beach preservation study purposes (Martins and Pereira, 2014).

Among studies and mapping works, coastal change monitoring typically utilized using total station and Global Navigation Satellite System (GNSS) survey technique to acquire spot heights along interest area as studied by Zimmerman et al., (2020) and Booysen (2017). Apart from that, Yusoff (2019) discussed advanced geospatial survey technology used for coastal monitoring research, which can be categorized into two. The first category focuses on coastline changes, and the second category focuses on the beach volume and berm height change of the sandy beach. Most coastline change studies normally popular in utilizing satellite imagery, airborne photogrammetry, and airborne LiDAR mapping. Although, coastal volume changes and berm height changes are dominant to utilized UAV photogrammetry, GNSS observation, bathymetry echo sounder, UAV LiDAR, mobile LiDAR, and terrestrial Laser Scanner (TLS). Through all the geospatial technologies, accuracy is one of the important criteria that need to be considered for volume mapping. Overall advanced geospatial technologies criteria are summarized in Table 1.1.

Table 1.1 Geospatial-based survey technologies (Yusoff et al., 2018)

Technology	Flight	Flight Restriction	Costing	Production Rate	Coverage Area	Accuracy
Satellite Remote Sensing	-	Tropical region cover with cloud	ten thousand	Satellite dependend	big area	m
LiDAR	complex	Weather condition	a hundred thousand	automated, faster	Large area and not practical for a small area	cm and mm
Terrestrial Laser Scanner	No	No	a hundred thousand	automated and faster	Limited coverage	cm
Airborne plane	Overlap and side lap needs to be considered	Must fly during day time and need a clear sky	a hundred thousand	Time-consuming	Large area and not practical to cover small area	cm
Total Station	No	No	thousand	Time-consuming	Limited coverage	mm
Mobile Laser Scanning	No	No	a hundred thousand	automated and faster		cm
GNSS	No	No	thousand	automated and faster	Limited coverage	mm
UAV (Drone)	Overlap and side lap consideration	Fly during the day, Weather condition	thousand	automated and faster	small and large area	cm

Table 1.1 shows the advanced geospatial technologies of LiDAR, TLS, Total Station, and GNSS able to do millimeter level accuracy in survey mapping. Equally important, satellite imagery, manned aircraft mapping, MLS, and drone/UAV able to perform level mapping measurement. All advanced geospatial technologies are capable of gaining accurate maps. Among the advanced geospatial technologies, UAV photogrammetry technology is less expensive mapping, complying mapping at eroded beach landform and the inaccessible place.

Table 1.2 shows the UAV mapping factors that have been studied by many researchers for the past few years (The detail of each literature review of Table 1.2 are depicted in section 2.7).

Table 1.2 Recent optimization UAV photogrammetry mapping

Factor	No of Literature review
Camera setting	2
UAV altitude	5
Distance between GCPs	3
GCPs distribution	11
Image overlap	2
Conventional mapping	1
Point cloud process	3
UAV Image capturing	2
Flightpath	4
DEM	6
volume effect	1
Calibration approach	2
Linear Landform	5
Wide area landform	18
UAV Calibration	2

Table 1.2 lists the numbers of literature reviews that included recent optimization UAV photogrammetry mapping methods. Table 1.2 also shows the research gaps that can be categorized into two aspects, optimization of UAV mapping method for beach volume measurement and modification of SfM-MVS photogrammetric volume formula for sustainable environment monitoring study at the linear beach area.

The first research gap aspect is about the optimization of UAV mapping method for beach volume measurement. The lack of studies on linear beach volume measurement by many aerial mapping and optimized UAV mapping method among studies is depicted in Table 1.2. Wide area landform mapping is the most popular UAV optimize mapping method with 18 studies and 5 of the UAV optimize mapping method for linear landform mapping. Hence, linear mapping such as beach coastline area is not a popular area and optimized method to investigate by many researchers. Apart from that, an optimization method for linear mapping sandy beach volume mapping using UAV has not described the effect of UAV camera parameters, GCPs distribution, and variation of UAV altitudes from the mapping. The evaluation by UAV photogrammetric practitioner of which UAV flying height altitude levels is optimum to implement is challenging, due to missing comparative work that assesses the UAV mapping different altitude measurements against a UAV camera parameter and GCPs distribution. Furthermore, indirect georeferenced UAV mapping using Ground Control Points (GCPs) is one of the popular methods implemented by many UAV mapping user such as Long et al. (2016); Drummond et al. (2015); Uto et al. (2017); Kim et al. (2017); Ma et al. (2016); Papakonstantinou et al. (2016); Scarelli et al. (2017); Suganuma et al. (2017); Turner et al. (2016); Gonçalves and Henriques, (2015); Yoo and Oh (2016); Yoshinao Matsuba (2017). However, most of the UAV mapping done for beach mapping used a non-optimal method such as the low altitude mapping like La Salandra et al. (2020), and bundle amount of GCPs across the beach mapping area may increase the time work procedure and image processing as stated by Yu et al. (2020). Hence, further investigation needs to be achieved to understand the change of 3D morphology of beach volume over the effect of UAV camera parameter, GCPs, and variation of UAV altitudes on the linear beach volume mapping.

The second research gap aspect is about the modification of SfM-MVS photogrammetric volume formula for sustainable environment monitoring study at the linear beach area. The proprietary SfM-MVS photogrammetric volume formula has no algorithms information used for particular software (Verhoeven et al., 2015; Smith et al., 2015;). Equally important, Fraser and Congalton (2018) and Rhodes (2017) suggested plenty of investigation need to be done based on SfM-MVS software with some parameters investigation. Apart from that, all UAV users have implemented the study on uncalibrated Ground Sample Data (GSD) parameter usage for photogrammetric SfM-MVS volume formula calculation, except for He et al. (2019) that used stockpile vessel as the dimension volume formula from UAV photogrammetry SfM-MVS volume formula. So, the investigation and modification of the SfM-MVS photogrammetric volume formula investigation on the calibrated Ground Sample Data (GSD) parameter supports the optimized volume determination method accurately using Unmanned Aerial Vehicle (UAV) photogrammetry mapping to minimize work time and less laborious beach mapping work for sustainable environment.

Based on the two aspects of research gaps discussed, the invention of accurate beach volume measurement from optimized photogrammetric volume formula modification using optimal altitude UAV mapping, and optimal GCPs distribution are the novelty of this study. The methodological of this study is further to minimize working time, perform less laborious work, and produce more accurate volume measurement for beach volume mapping measurement.

1.3 Research Aim and Objectives

The aim of this research is to invent an optimized volume determination method accurately using Unmanned Aerial Vehicle (UAV) photogrammetry mapping to minimize work time and perform less laborious beach mapping work for a sustainable environment study. Hence, the three objectives of the study are as follow:

1) to investigate the camera calibrations, UAV altitudes, and GCPs distribution for optimized beach volume UAV mapping method;

2) to modify the SfM-MVS photogrammetric volume formula for the development of accurate and optimized beach volume mapping method; and

3) to analyze the optimized beach volume mapping method produced.

1.4 Scope and limitations

There are several limitations that needs to be addressed in this research. This study is focused on the development of the optimized and accurate method for beach volume measurement along the coastline. Moreover, this study is conducted within several scopes of area as stated below.

1.4.1 Study Area

Malaysia's coastline area covers about 1,300 km of Malaysian beaches, and all of the beach area experiencing erosion effects (Ong, 2001). Therefore, the area of study only covers some parts of the Malaysian coastline beach area where beach erosion phenomena are commonly happened. The selected area to investigate as the datasets are Desaru Beach, Johor, UTM field, and two areas of Irama Beach, Kelantan as shown in Figure 1.1 below.

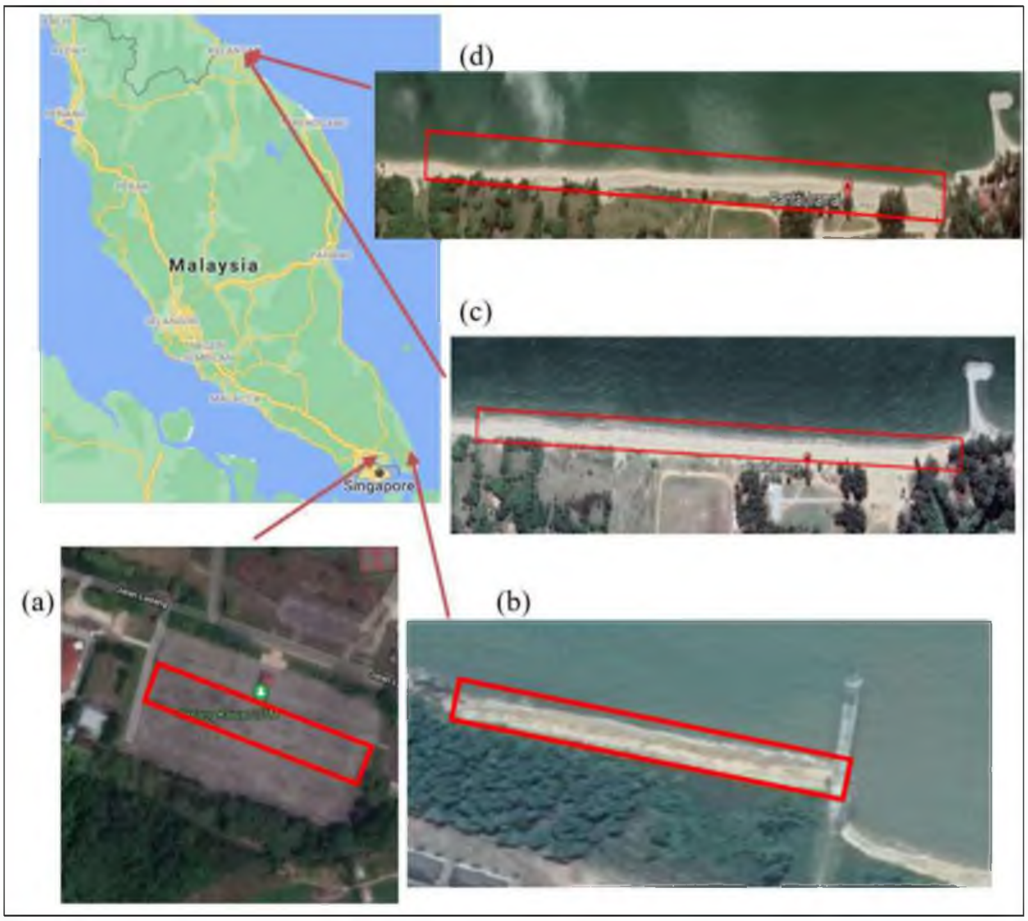

Figure 1.1 Image of study areas; (a) UTM field, (b) Desaru Beach, Johor, and (3) Irama Beach 1, Kelantan, and (4) Irama Beach 2, Kelantan

Figure 1.1 shows the area of the study performed around Malaysia with linear mapping area mapping. Figure 1.1 (a) shows a UTM field with a 400 m x 25 m dimension area categorized as linear site mapping. This dimension is the same as the beach mapping space, but with a flat mapping area which is used to investigate optimized UAV volume mapping measurement. The other areas include Desaru Beach with 100 m x 15 m dimension area (Figure 1.1 (b)), Irama Beach 1 with 800 m x 15 m dimension area (Figure 1.1 (c)), and Irama Beach 2 with 1200 m x 15 m dimension area (Figure 1.1 (d)). The investigations of the UAV beach volume measurement trend and mapping behavior from various GCPs distribution, different UAV altitude mapping, and optimized photogrammetric volume formula modification are performed at all study areas. However, the investigation of Desaru Beach and Irama Beach 2 datasets are used for the validation area of the study development. Both two sides are **the same morphology as the majority of Malaysia's beach cover area.**

1.4.2 Optimization Method

The optimization method in this study is the invention of the less laborious work and accurate way on the determination of volume mapping measurement. This method is categorized to UAV mapping approach of GCPs distribution and UAV altitude mapping, and the volume formula calculation with more accurate, appropriate and trust method with modification of UAV camera parameters in volume formula determination.

This study highlights three optimized UAV mapping approach: the UAV volume mapping measurements specified in the GCP distributions, UAV altitude mapping, and photogrammetric volume formula. UAV various GCP distributions are implemented with 3, 4, 5, 6, 8, 10, 15, and 20 GCPs and well-distributed along the mapping area. Subsequently, different UAV altitude mapping is investigated according to study areas at 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 80 m, and 100 m altitude. Lastly, optimized photogrammetric volume formula modification is studied from modification of photogrammetric volume formula with calibrated GSD using calibrated laboratory camera focal length parameter and calibrated camera pixel size. The validations of the optimized beach volume UAV mapping method and the optimized photogrammetric volume formula are compared to TLS volume measurements.

The SfM-MVS in-situ UAV camera calibration, GCPs distribution, and UAV altitude mapping are the optimized mapping condition that were studied to investigate the volume measurement mapping for objective 1, modification of photogrammetric volume formula for accurate mapping are studied for objective 2, and analysis of the produced optimized beach volume UAV mapping method for objective 3. All of the objectives led to the invention of the accurate optimized beach volume mapping method to minimize work time and less laborious beach mapping work.

1.4.3 Photogrammetric Volume Modification for Coastline Area

The area of volume measurements is located along the beach berm that is close to seawater which indicates the coastline area studied by many beach erosion researchers, as shown in Figure 1.2. The areas of study are Desaru Beach, Johor and Irama Beach, Kelantan area involved narrow width space of beach berm which is approximately 15 meters. Figure 1.2 shows the eroded section of the beach that was investigated in this study.

Figure 1.2 Beach berm area

The point cloud generation from UAV images produced DSM in raster format, and the photogrammetric volume measurement can be done in SfM-MVS based software. The Pix4D software volume calculation is based on the Digital Surface Model (DSM); the raster format of the area selection gives the amount of volume as depicted in Figure 1.3. The formula used to calculate the volume and PiX4D volume formula concept is derived in Sub-section 2.6.2.

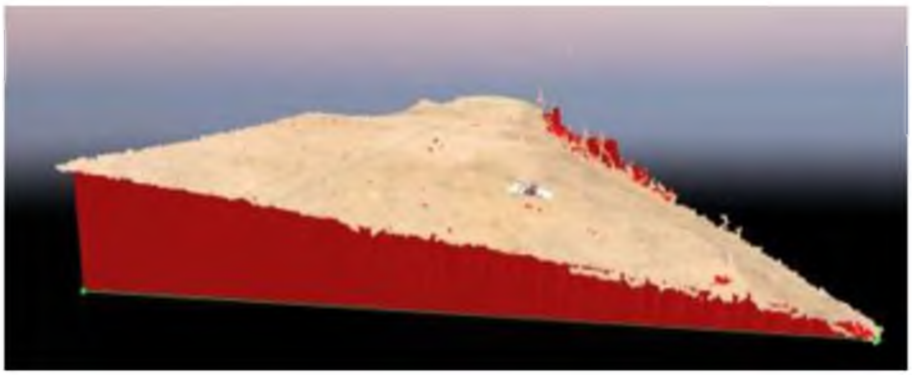

Figure 1.3 Volume calculation cross-section based on Pix4D mapper software

Modification of photogrammetric volume formula is performed by deriving selected raster cell heights, Hi, and selected raster area dimension, (a x b) from volume and area measurement calculation in PiX4D mapper software. Then, expansion of the GSD formula from the existing volume formula is derived and modified for the development of optimized volume measurement formula (see Sub-chapter 3.5.4 for better understanding).

1.5 General Methodology

After deliberating on the scope and limitation of the study, a brief research method is depicted in Figure 1.4 for a better understanding of what the investigation methods are all-about to achieve the research aim and objectives.

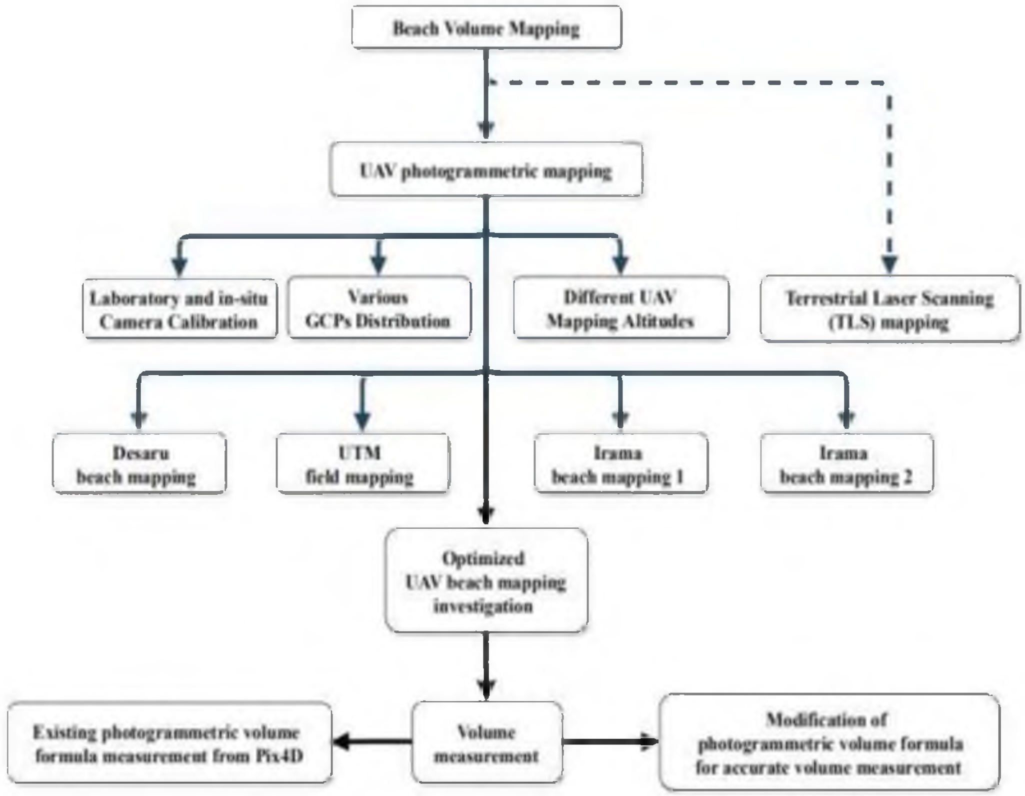

Figure 1.4 Brief research method

Figure 1.4 shows the brief research method involved in the study. Four areas of study with UAV camera calibration, various GCPs distribution numbers, different UAV altitude mapping are introduced to investigate the optimized UAV beach volume mapping measurement method. Post-processing of UAV datasets and modification of SfM-MVS photogrammetric are performed for the development of optimized volume formula with the comparison of the existing photogrammetric volume formula and validation using TLS volume measurement.

1.6 Research Contributions

The contribution of this study can be categorized into intellectual worldwide knowledge contribution and nation development contribution. The study envisaged the new invention of accurate UAV beach volume measurement through an optimized beach volume mapping method that minimizes work time and less laborious work beach mapping. The invention method is advantageous and leads to intellectual worldwide knowledge contribution as follow:

i) UAV beach mapping application can save time and less control survey work when applying the optimized method introduced in this study.

ii) Increasing the UAV site mapping area with more working hours can be done with an occupied UAV battery power supply.

iii) The modification of photogrammetric volume formula for high altitude UAV mapping method contribute to minimized survey working time, and less laborious work could be performed with accurate beach volume mapping

iv) The optimized method in this study can improve the data collection method for excessive eroded coastal area monitoring that requires less working time.

v) The result of volume measurement in this study can also be used for the coastal change model that can be extended for the prediction model by adding other coastal behaviours parameters on the region study area.

vi) Optimized mapping planning guidances to the UAV linear mapping that gives an accurate volume output for many areas of linear mapping side like the lake, river hill, road line, and others.

Furthermore, the national development contribution also gets the benefit as the coastal environment behaviours and beach change pattern are the factors for the **authorities' decision**-making to manage the coastal area. Some studies have discussed the relation of coastal change behaviours and coastal management as described by Tonyes et al. (2015), who states that the dynamics of sand changes is vital for coastal management care that indicates beach erosion and accretion as an important element. The detail of beach morphology changes and an island vulnerability understanding can give prediction models information as a guide for decision-makers by the authorities in the future, as stated by Brenner et al. (2018). Moreover, weather changes make the decision-makers, stakeholders, and engineers interested in the effect of future coastal development gain from productive and optimized beach volume mapping (Zikra et al., 2015).

Apart from that, the local authorities like the Department of Irrigation and Drainage Malaysia, the housing development, the National Parliament with an annual budget can come out with the right decision to manage the coastal and beach area by applying a low-cost budget from optimized beach volume mapping. Besides, the residents along the coastal area can clearly see the coastal change behaviours to happen around them with fast result gain from the discovered method.

1.7 Structure of Thesis

This thesis is divided into five chapters: introduction, literature review, research methodology, results and analysis, and conclusions.

Chapter 1 (Introduction): The concept of the entire research is summarized in Chapter 1. It is outlined by the background of study, problem statement, research aim and objectives, scope and limitations (study area, optimization method, photogrammetric volume modification for coastline area), general methodology, research contributions, and structure of thesis.

Chapter 2 (Literature Review): The all-inclusive literature review about the thesis motivation, novelty, and research gaps are covered in Chapter 2. It consists of an introduction, beach erosion, beach mapping and monitoring (coastline errors and uncertainty, coastline change rate), recent beach monitoring studies, beach volume measurement, UAV photogrammetry beach mapping, (SfM and MVS in photogrammetry, UAV beach volume mapping), optimization of UAV photogrammetry mapping, UAV photogrammetric volume calculation studies, and chapter summary to conclude the reviews all-about.

Chapter 3 (Research Methodology): This Chapter 3 explains the entire method of the research. The organized process and research activities include the introduction, research methodology, research instruments (UAV photogrammetry, Global Navigation Satellite System (GNSS) instrument, Ground Control Points (GCPs), Terrestrial Laser Scanner, camera calibration tools), data collections (data collection at Desaru Beach, Johor, data collection at Universiti Teknologi Malaysia (UTM) field, data collection at Irama Beach, Kelantan, GCPs coordinate processing, UAV image mapping processing), research stages (research stage 1, research stage 2, research stage 3, research stage 4, research stage 5, research stage 6), analysis method, and chapter summary to recapitulate the chapter.

Chapter 4 (Results and Analysis): The results, analysis, and discussion are explained in details with following sub-chapter; the introduction, analysis of in-situ SfM focal length camera calibrations parameter from UAV volume measurements, and comparison to initial camera focal length and laboratory camera focal length calibration, discussion for stage 1 data analysis, analysis of UAV altitudes mapping effect on beach volume accuracy, discussion for stage 2 data analysis, analysis of GCPs distribution effect on beach volume accuracy, discussion for stage 3 data analysis, modification of photogrammetric volume formula for the development of optimized photogrammetric volume formula, discussion for stage 4 data analysis, comparison of optimized photogrammetric volume formula to the existing photogrammetric volume formula, discussion for Stage 5 data analysis, comparison of optimized photogrammetric volume formula measurement and existing optimized photogrammetric volume formula measurement to Terrestrial Laser Scanning (TLS) volume measurement, discussion for stage 6 data analysis, and ended with summary of the Chapter 5.

Chapter 5 (Conclusions and Recommendations): Finally, this chapter elaborates the research conclusion and the conclusion for each objective and recommendations for future related studies.

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