TOWARDS UNIFICATION OF VERTICAL DATUM FOR SABAH AND SARAWAK USING GRAVIMETRIC GEOID MODEL

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Dedicated to my beloved father Othman Ismail and mother Mariam Hameed,
my siblings,lecturers and friends

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ABSTRACT

Sabah and Sarawak have adopted various local vertical datums that tied to mean sea level referring to tide gauges. The use of various datums may implicate height inconsistencies in these two states. This study aims to evaluate the potential of gravimetric geoid model as uniform vertical datum for Sabah and Sarawak. The objectives of this study are to assess the existing geoid model and to compute vertical datum offset. East Malaysia Gravimetric Geoid (EMG03C) model and Global Positioning System (GPS) levelling are the primary data used in this study. The assessment of geoid models involved in this study are EMG03C model, fitted geoid model EMGEOID05 and EGM2008. These geoid models were evaluated with GPS levelling derived geoid height and the comparison were made in absolute and relative method. Meanwhile, the vertical datum offset value between Sabah 97 Datum and Pulau Lakei Datum was computed by comparing the mean bias of geoid height differences based on 108 GPS levelling points. Based on absolute geoid assessment, this study found that the fitted geoid model has good performance over Sabah which is $\pm$ 6 cm and the accuracy of geoid model is degraded over Sarawak of $\pm$ 30 cm.

The possible reason of low accuracy of fitted geoid model in Sarawak due to the model has been fitted to the mean sea level at Sabah 97 Datum. Hence, for local application vertical datum offset need to be considered. Based on relative assessment, gravimetric model demonstrate the difference Root Mean Square (RMS) of $\pm$ 3 cm and $\pm$ 2 cm for 60 km baseline over Sabah and Sarawak respectively.

This demonstrates the feasibility of relative GPS levelling and gravimetric geoid as alternative technique in height determination for engineering and construction project. In addition, the result also shows that vertical datum offset between Sabah 97 Datum and Pulau Lakei Datum using gravimetric geoid model and GPS levelling data is about 0.257 m. Therefore, gravimetric geoid is suggested as suitable unified vertical datum for Sabah and Sarawak. In conclusion, gravimetric geoid-based vertical datum has a potential for modernizing the height system in Sabah and SarawaK.

ABSTRAK

Sabah dan Sarawak menggunapakai pelbagai datum tegak tempatan yang diikat kepada min aras laut dan dihubungkan dengan stesen pasang surut. Penggunaan pelbagai datum ini memberi implikasi kepada ketinggian yang tidak konsisten kedua-dua negeri ini. Kajian ini bertujuan menilai potensi model geoid gravimetrik sebagai satu datum yang seragam untuk Sabah dan Sarawak. Objektif kajian ini ialah menilai model geoid sedia ada dan menghitung ofset datum tegak. Data model geoid gravimetrik Malaysia Timur (EMG03C) dan data ukur aras Sistem Penentududukan Sejagat (GPS) merupakan data utama yang digunakan dalam kajian ini. Dalam kajian ini, penilaian model geoid yang terlibat adalah model EMG03C, geoid suaian EMGEOID05 dan EGM2008. Model-model ini dinilai menggunakan data ukur aras GPS berasaskan terbitan ketinggian geoid dan perbandingan dibuat dalam keadaan mutlak dan relatif. Sementara itu, nilai ofset datum tegak antara Datum Sabah 97 dan Datum Pulau Lakei dihitung dengan membandingkan nilai bias min daripada perbezaan geoid berasaskan 108 titik ukur aras. Berdasarkan penilaian geoid mutlak, kajian ini mendapati prestasi model geoid suaian adalah lebih baik di kawasan Sabah dengan ketepatan $\pm$ 6 cm dan berkurangan di Sarawak sebanyak $\pm$ 30 cm. Kemungkinan faktor penyebab ketepatan model suaian berkurangan di Sarawak adalah kerana model suaian disepadankan dengan min aras laut pada Datum Sabah 97. Oleh itu, dalam aplikasi tempatan ofset datum tegak perlu dipertimbangkan. Perbandingan relatif geoid gravimetrik menunjukkan perbezaan punca min kuasa dua (RMS) sebanyak $\pm$ 3 cm dan $\pm$2 cm untuk garis dasar 60 km, masing-masing di Sabah and Sarawak. Ini menunjukkan kebolehlaksanaan teknik ukur aras GPS relatif dan geoid gravimetrik sebagai teknik alternatif dalam penentuan ketinggian untuk projek kejuruteraan dan pembinaan. Selain itu, nilai ofset datum tegak ukur yang dikira menggunakan data aras GPS dan model geoid gravimetrik antara Datum Sabah 97 dan Datum Pulau Lakei telah menunjukkan perbezaan sebanyak 0.257 m. Oleh yang demikian, geoid gravimetrik didapati sesuai untuk digunapakai sebagai datum tegak seragam di Sabah dan Sarawak. Kesimpulannya, datum tegak berasaskan geoid gravimetrik mempunyai potensi dalam memodenkan sistem penentuan ketinggian di Sabah dan Sarawak.

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LIST OF ABBREVIATION

BM	Benchmark
EGM2008	Earth Geoid Model 2008
EGM96	Earth Geoid Model 1996
EMG03C	East Malaysia Gravimetric Geoid Model
EMGG05A	East Malaysia Fitted Geoid Model
FFT	Fast Fourier Transformation
GGM	Global Geopotential Model
GDM2000	Geocentric Datum Malaysia 2000
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
DSSM	Department Survey and Mapping Malaysia
LSD	Land Survey Datum
MSL	Mean Sea Level
IDW	Inverse Distance Weighted Method
LSC	Least Square Collocation
RMSE	Root Mean Square Error
PPM	Part Per Million
NGVD	National Geodetic Vertical Datum

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Height of points on the surface of the earth is required since the beginning of human existence and it is importance for variety of scientific and engineering applications. One of earliest surveying equipment is water level which was used by Romans during occupation of Egypt in 15 BC. This water level is aligned perpendicular to direction of gravity, forms a level surface. By sighting at one end of the tube, a level line can be determined. This instrument although a simple in nature, water level were successfully used in constructing Roman aqueducts, connecting Nile river and Red Sea and establish extensive system in the Euphrates Valley (Mustafar,2005).

In recent year, a system of height control is realized by the establishment of a precise leveling network whereby the value of a certain point may be defined .These heights commonly refer to a specific vertical datum which is typically tied to mean sea level. The precise levelling technique has been embarked to transfer height from benchmark to other benchmarks by accumulating height difference.

Department Survey and Mapping Malaysia (DSSM) has been authorized to establish national precise levelling network since early 1960's (Ses and Mohamed, 2009). Normally, the height control of a country will be updated after a certain period for example in 50 year (Aziz, 2005). The establishment of vertical network of a country will take a long time to be performed. There are some factors contribute to this issue for example the development of a country, the area, the cost and the adequate human resources. The measurement is done part by part somehow due to fulfil the requirement rather than a proper scientific planning. In fact, height is important for development and planning for a country.

The Malaysia vertical network has been developed separately into Peninsular Malaysia, Sabah and Sarawak. The first precise leveling was established on 1967 refer based on mean sea level known as Land Survey Datum 1912 (LSD1912) at Port Klang. Due to many inadequate and problems in LSD1912, DSSM take initiative to establish new vertical control for Peninsular .As a result, measurement second precise leveling network was completed in 2000 and the complete adjustment is been performed. The precise levelling network was defined based on mean sea level datum at Port Klang known as Peninsular Malaysia Geodetic Vertical Datum (PMGVD1994) and the adjusted height was based on Helmert orthometric height system (Ses and Mohamed, 2009).

In East Malaysia, the leveling networks were referring to various datums. According to Azhari (2003), there are six vertical datums currently in used (DSSM, 2008). Kota Kinabalu datum has been defined as vertical datum for Sabah Geodetic Vertical Reference Network (Aziz, 2005). For Sarawak, the vertical datum has been referring to several datums such as Pulau Lakei datum, Bintulu datum, and Original datum, Limbang Datum, Merapok Datum and Sabah Datum (Nordin et. al 2005). The variety of vertical datum may provide luxury of choosing vertical datum for vertical

controls but a problems will arise when connections are made between benchmarks originating from separated datums (Mohamed, 2003).

In addition, it is an uncommon practice in surveying to refer to multiple vertical datums. It is well known that unification of vertical datum is a global problem especially for region having various vertical datums. Currently, there are hundreds of national and regional height system exists (Rummel, 2012). Therefore, to harmonize the vertical datum over East Malaysia, vertical datum unification is crucial to create a reliable and uniform for all geodetic activities (Ses and Omar, 2000).

Nowadays, one of alternative method to unify vertical datum is by using geoid model (Amos, 2009). Geoid is an equipotential surfaces of earth gravity field which approximately coincide with mean sea level. When GPS receiver is used on the benchmark such a model enables each of the vertical datums to have an offset calculated, and so the datums can be related to each other.

Nowadays, GPS offers the position in three Dimensional position has been defined relative to ellipsoid.GPS is referenced to a geocentric ellipsoid and heights obtained are not in relation to geopotential surface of the earth gravity field. In most cases, the users need height referenced to gravity field, which determine fluid flows and to be consistence with the existing infrastructure. To convert GPS-derived ellipsoidal height (h) to orthometric height (H), the precise geoid height is needed.

The geoid height can be obtained from gravimetric geoid model. The precise gravimetric geoid over East Malaysia is known as EMG03C model has been computed in MyGEOID project (DSSM, 2003). This model was computed primarily based on dense airborne gravity survey and terrestrial gravity data. The precise gravimetric geoid can be used to connect one local vertical datum to another and verification of apparent sea slope. According to DSSM (2003), the relative accuracy of East Malaysia gravimetric geoid model is about ±5 cm.

1.2 Problem Statement

Ideally, all height system must refer to a single vertical datum. This datum typically close to mean sea level so that height of terrain has natural meanings of height above mean sea level. Due to mean sea level is not lie on geoid, the deviation is called sea surface topography and is estimated about ± 1 to 2 meter globally (Balasubramia, 1994). As a consequence, local vertical datum varies each other by certain amount of offset.

Current levelling network over East Malaysia refer to various vertical datum. The unification of vertical datum using traditional method is no longer sufficient and possible in term of cost and time. Moreover, East Malaysia has rugged topography feature which make precise levelling technique is tedious and hard to be undertaken. Therefore, it is not feasible to unify the vertical datum using precise levelling adjustment whole over East Malaysia. As alternative, the East Malaysia gravimetric geoid model is one of the option and GPS provide as tool in realise the method.

In this study, local vertical datum is unified using precise gravimetric geoid model. The height above gravimetric geoid vertical datum will represent a homogenous and consistent height in orthometric height system. To obtain the orthometric height, the GPS observation can be done over the area that has gravimetric geoid model coverage. The conceptual of vertical datum unification is based on the Figure 1.1.

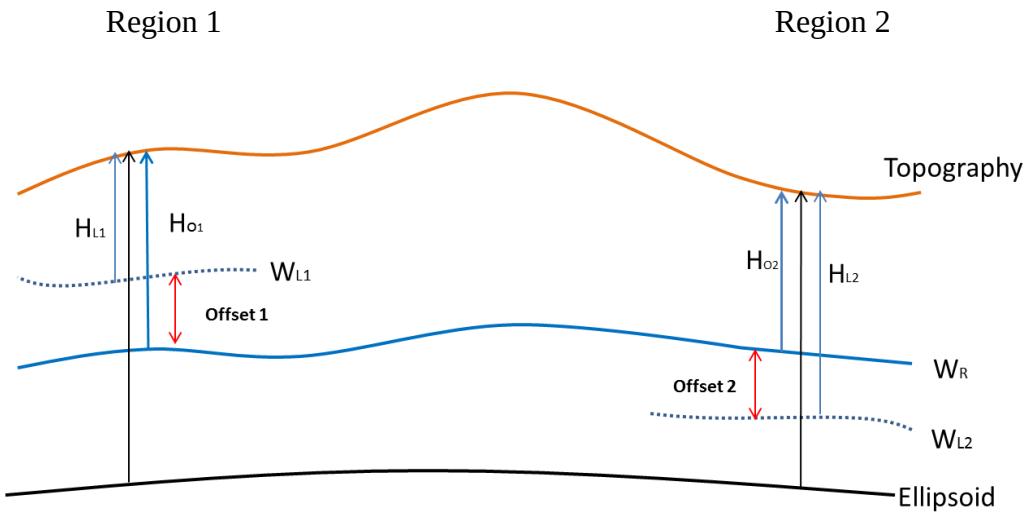

Figure 1.1: Conceptual of vertical datum unification over Sabah and Sarawak

Based on the figure, there are two regions 1 and 2 that have local vertical datum 1, W_{L1} and local vertical datum 2, W_{L2}. H_{L1} is local orthometric height defined with respect to local mean sea level surface called W_{L1}. The local vertical datum is realized by precise levelling and tide gauges. This height is inconsistencies with the height H_{L1} because refer to different level surface. The W_R is gravimetric geoid which is an equipotential surface of earth gravity field used to connect W_{L1} and W_{L2}. The height defined with respect to W_R is H_o called orthometric height. Based on the figure, H_{o1} and H_{o2} are consistent because based on the same datum and refer to same level surface. The realization of a unified vertical datum achieves using gravimetric geoid of East Malaysia, W_R. To link the local level surface, the regional geoid model is used by

determined local vertical offset 1 (offset 1) and local vertical datum 2 (offset 2). This offset can be used to transform height between two different height systems. This can be achieved by computing vertical datum offset.

1.3 Research aim and objectives

The aim of this study is to evaluate the potential of gravimetric geoid model as unified vertical datum for Sabah and Sarawak. To achieve the aim, there are two objectives are embarked;

a) To assess the existing geoid model

b) To compute vertical datum offset

1.4 Research Question

The research questions are addressed as follow:

a) Can Gravimetric geoid model use in vertical datum unification geoid model?

b) What is the accuracy of available gravimetric geoid model in East Malaysia?

c) What is the best approach to unify vertical datum in Sabah and Sarawak?

d) How to realize gravimetric geoid as vertical datum?

e) How to relate between the local vertical datum using gravimetric geoid model?

1.5 Significances of Study

This study contributes an alternative method in unification of vertical datum for Sabah and Sarawak. The establishment of a unified vertical datum using gravimetric geoid model is an effort to modernize the height system over Sabah and Sarawak. In addition, the practical assessment of geoid model and vertical datum offset contribute to vertical datum unification over East Malaysia.

1.6 Scope and Limitation of Study

The scope of this study is limited to the aim and objectives of the study. The East Malaysia Gravimetric Geoid Model (EMG03C) is adopted as vertical reference datum to unify Sabah and Sarawak datum. The data used for assessment of gravimetric geoid is limited to GPS levelling data. In addition, the computation of vertical datum offset is involved two vertical datums which are Pulau Lakei and Kota Kinabalu datum. The following subsection describes the detail about the scope of the study.

1.6.1 Study Area

The focus area is selected in Sabah and Sarawak. This area is very rugged topographical area and mountainous area where the levelling network is very hard to be carried out. In addition, the various height datums have been existed over East Malaysia. The existing levelling infrastructure and the vertical datum can be found in Appendix B and Appendix C.

Figure 1.2: Study area (image captured from Google Map)

1.6.2 Geoid Model

East Malaysia Gravimetric Geoid (EMG03C) is primary used in this study. This model is computed in 2003 during MyGEOID project (DSSM, 2003). This relative accuracy of the gravimetric geoid model is about ± 5 cm which is better than available geoid model in Sabah and Sarawak (Nordin et. al, 2005). The model is made available for this study by DSSM for this study. In addition, the fitted geoid model and EGM2008 are secondary data used for analysis.

1.6.3 Vertical Datum

There are various vertical datum over Sabah and Sarawak area as mentioned in background. In this study, it is assumed that two local vertical datum exist for Sabah and Sarawak. This due to the GPS levelling data on collocated benchmarks are subjected to both vertical datum. This information is important because the local vertical datum offset will be computed based on both datums.

1.6.4 GPS Levelling Data

The GPS levelling project was conducted on 2004 and 2005 by DSSM. It is believed the data has a good accuracy. The GPS coordinate information is given in

GDM 2000 coordinate system. GPS levelling data on collocated benchmark in Sabah and Sarawak are utilized to unify vertical datum and used in estimating vertical datum offset.

1.6.5 Data Processing

The study is limited to data processing involve the interpolation of geoid height from geoid model. This process was done to transform ellipsoidal height from GPS to orthometric height system. The validation of EMG03C is based on GPS levelling. Besides, the estimation of vertical datum offset and modelling will be computed in the data processing.

1.6.6 Software

The GEOCOM program (DSSM, 2005) is used to interpolate the geoid height from EMG03C and EMGG05A.

1.6.7 Data Assessment and Analysis

There are two validation is conducted in this study. First, verification of gravimetric geoid compared to geometric geoid over Sabah. This can be obtained using absolute and relative method. The

1.7 Research Methodology

The research methodology generally described as following. The study is initiated by reviewing the current issues in vertical datum unification for Sabah and Sarawak. Based on Figure 1.3, the literature review has been conducted. The height system and concept of vertical datum unification study is been understanding. After the objective has been outline, the data acquisition and data compilation is made. Basically, the gravimetric geoid model and GPS data is required to unify vertical datum in Sabah and Sarawak. The GPS levelling data on collocated local Benchmarks are compiled obtained from DSSM. The development of vertical datum is been implemented using interpolation technique. The result and analysis will be explained in Chapter 4.

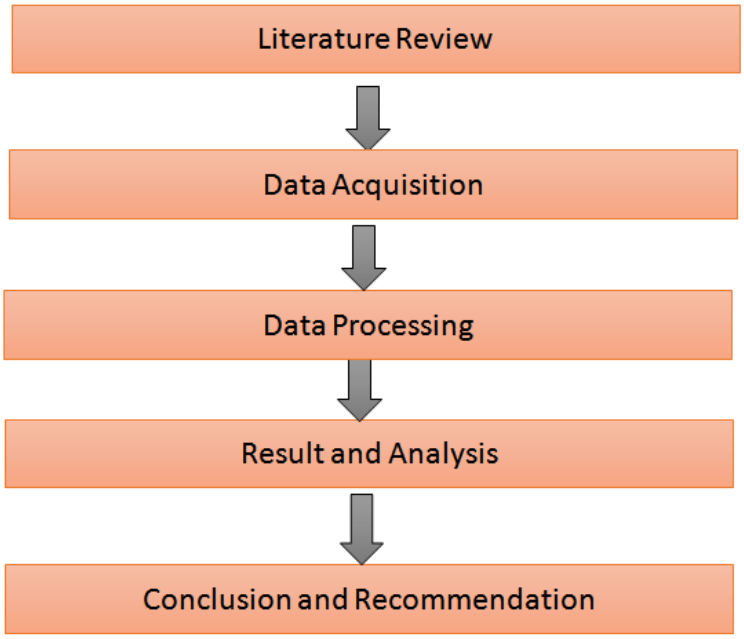

Figure 1.3: Flowchart of general methodology

1.8 Thesis Structure

The structure of this thesis is divided into five chapters. The description of each chapter is summarized as follow:

Chapter 1 describes the background of study, objective, scope and limitation of study and significance of study and general methodology.

Chapter 2 describes literature review that related to the study. Basic height system and unification of vertical datum is been presented. The development of vertical datum offset is reviewed.

Chapter 3 discussed the research methodology employed in this study. The details about phase development generally are explained in this chapter.

Chapter 4 discusses about the result of geoid asssessment and vertical offset computation.

Chapter 5 concluded the research findings of the study and recommend the further study to improve the vertical datum unification study for Sabah and Sarawak.

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