HEIGHT MODERNIZATION USING FITTED GEOID MODELS AND MYRTKNET

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ABSTRACT

The purpose of this study is to examine the strategies for rapid height determination using the current Global Positioning System (GPS) technology. With steady economic growth in Malaysia since 1998, more highways, federal and states road have been built or have been widen. These development processes have somehow destroyed, damaged or disturbed the levelling benchmarks located along the routes. Currently the conventional method to require the levels of these benchmarks is costly and time-consuming. This study focuses on the theory, computation method and analysis of WMGeoid04 and WMGeoid06A revised models using GPS *Virtual Reference Stations* (VRS) technique for rapid height determination. The computation of WMGeoid04 and WMGeoid06A precise fitted geoid models was based on least squares collocation using the existing gravimetric geoid and newly observed geometric geoid separation. Analysis of the precise fitted geoid models have shown that the formal fitting errors were less than 4 cm. In addition, the validation process with external data sets has achieved 5 cm accuracy in terms of Root Mean Square (RMS). Assessment of GPS station coordinate consistency indicates the achievable accuracy (at 95% confidence region) from VRS technique is better than 3 cm horizontally, and better than 6 cm vertically. Further analysis using orthometric height comparison between published and derived height of levelling benchmarks using the combination of fitted geoid models with VRS technique have shown that the differences are better than 6 cm. The results showed that GPS levelling with precise fitted geoid model and VRS technique is relatively better than second class levelling survey at a lesser cost and time, and could be used to update existing levelling benchmark and establishing a new levelling routes in Malaysia.

ABSTRAK

Kajian ini dilakukan bertujuan untuk meneliti strategi penentuan ketinggian secara pantas dengan menggunakan teknologi *Global Positioning System* (GPS) semasa. Dengan peningkatan ekonomi yang berterusan sejak 1998, pembinaan dan pelebaran rangkaian lebuhraya, jalan persekutuan dan negeri telah dilakukan. Proses pembangunan ini walaubagaimana pun telah memusnah, merosakan atau mengganggu tanda aras yang dibina di sepanjang laluan tersebut. Pada masa kini, proses ukuran semula secara konvensional adalah tidak praktikal, di mana akan melibatkan kos yang tinggi serta memerlukan masa yang panjang untuk disudahkan. Kajian ini memberi fokus utama kepada teori, kaedah penghitungan dan analisa model geoid jitu kesepadanan WMGeoid04 dan model geoid tersemak WMGeoid06A menggunakan kaedah GPS *Virtual Reference Stations* (VRS) untuk tujuan penentuan ketinggian secara pantas. Hitungan model geoid jitu kesepadanan iaitu WMGeoid04 dan WMGeoid06A adalah berasaskan kaedah *least squares collocation* dengan menggunakan model geoid gravimetrik sedia ada dan pisahan geoid geometrik yang baru. Analisa keatas model geoid jitu kesepadanan telah menunjukkan bahawa selisih kesepadanan formal adalah kurang dari 4 sm. Tambahan dari itu, proses validasi dengan menggunakan set data berlainan telah mencapai ketepatan 5 sm berdasarkan *Root Mean Square* (RMS). Penilaian keatas koordinat GPS telah menunjukkan bahawa ketepatan (darjah kebersanan 95%) lebih baik dari 3 sm untuk komponen mendatar dan 6 sm bagi komponen pugak telah dicapai dengan menggunakan kaedah VRS. Analisa selanjutnya adalah membandingkan nilai ketinggian tanda aras antara nilai terbitan dan nilai hitungan dengan menggunakan kombinasi model geoid jitu kesepadanan dan koordinat dari kaedah VRS, telah menunjukan kesepadanan adalah lebih baik dari 6 sm. Hasil kajian menunjukkan ukuran aras GPS dengan menggunakan model geoid jitu kesepadanan dan kaedah VRS adalah lebih baik dari ukuran aras relatif kelas kedua pada kos lebih rendah dengan masa yang singkat. Kaedah ini boleh di gunakan untuk mengemaskinikan tanda aras sedia ada dan mewujudkan laluan ukuran aras baru di Malaysia

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LIST OF ABBREVIATIONS

DEM	-	Digital Elevation Model
DSMM	-	Department of Survey and Mapping Malaysia
EMPGN2000	-	East Malaysia Primary Geodetic Network 2000
GLONASS	-	Russian's Global Navigation Satellite System
GNSS	-	Global Navigation Satellite System
GPS	-	Global Positioning System
GRS80	-	Geodetic Reference System 1980
IGS	-	International GNSS Services
ITRF2000	-	International Terrestrial Reference Frame 2000
JICA	-	Japan International Cooperation Agency
JUPEM	-	Jabatan Ukur dan Pemetaan Malaysia
LSD1912	-	Land Survey Datum 1912
MASS	-	Malaysia Active GPS System
MSL	-	Mean Sea Level
MyRTKnet	-	Malaysia RTK Network
NCGS	-	North Carolina Geodetic Survey
NGS	-	National Geodetic Survey
NGVD	-	National Geodetic Vertical Datum
NHM	-	National Height Modernization
NHMS	-	National Height Modernization Study
NPLN	-	National Precise Levelling Network
NSRF	-	National Spatial Reference Frame
PMPGN2000	-	Peninsular Malaysia Primary Geodetic Network 2000
PMSGN94	-	Peninsular Malaysia Scientific Geodetic Network 1994
RMK	-	Rancangan Malaysia
RTK	-	Real Time Kinematic
SST	-	Sea Surface Topography

TEC	-	Total Electron Contents
TON	-	Tidal Observation Network
VRS	-	Virtual Reference Station
WGS84	-	World Geodetic System 1984

CHAPTER 1

INTRODUCTION

1.1 General Background

In the recent years, an accurate height of points is always being determined by a levelling technique that is usually referred as the adopted Mean Sea Level (MSL). *Jabatan Ukur dan Pemetaan Malaysia* (JUPEM), also known as the Department of Survey and Mapping Malaysia (DSMM) has been carrying out levelling survey to establish a precise levelling network for the whole country since the early 1960's. While the adjustment of the precise levelling network in Peninsular Malaysia has been completed in 1998, the re-adjustment process is still ongoing, with the levelling networks in Sabah and Sarawak are still not unified and always being referred to various vertical datum.

With the increasing capability of Global Positioning System (GPS) satellites and its computation techniques, the use of GPS for height determination has rapidly increased. This brings forward the question whether the slow and expensive levelling can be replaced by GPS, or at least, levelling errors can be controlled. There are two (2) different things to consider, which the accuracy of the GPS itself and also the accuracy of the geoid model that needed to transform heights above the ellipsoid into orthometric.

For several years, a precise geoid determination in Malaysia has been done with collaboration with other institutions locally and abroad. However, the previous geoid determination study was based on projects basis and concentrate on a small area that has dense gravity data with main goal is to compute a geoid model for whole of Malaysia. In 2003, JUPEM had carried out airborne gravity survey that covers whole of Peninsular Malaysia as well as in Sabah and Sarawak with the main objective is to compute precise gravimetric geoid models across the country.

In 2005, JUPEM has launched MyGEOID and MyRTKnet to provide public users with a complete infrastructure that can be utilized. The achievable accuracy with MyGEOID is around 5 cm (1σ) and 10 cm (1σ) for Peninsular Malaysia and Sabah and Sarawak respectively. These figures are still far from the anticipated accuracy of 1 cm (1σ) that has been achieved in certain area in Europe. The accuracy of MyGEOID can be increased with the densification of gravity data and more benchmarks observed with GPS.

Geoid determination has been one of the main research areas in Science of Geodesy for decades. With the wide spread use of GPS in geodetic applications, research institutes and relevant agencies responsible for geodetic positioning have invested million of dollars to precisely determine the local/regional geoid. All with an aim to replace the geometric levelling, which is a tedious measurement work compared to the GPS surveying techniques.

The National Height Modernization (NHM) program in the United States of America has been established to update the vertical component of the existing spatial geodetic reference framework. This program is meant for those areas with many geodetic monuments, destroyed either by development or compromised by seismic and subsidence activity. The North Carolina Geodetic Survey (NCGS) has conducted a National Height Modernization Study (NHMS) to compare the accuracies and staff-hour costs of elevations, determined by traditional levelling versus by using Global Positioning System (GPS). Similar cost comparison studies are being conducted as part of the National Height Modernization program in northern and southern California, especially in areas experiencing any crustal motion or subsidence.

The staff hour comparison between levelling and GPS has shown that the GPS survey took 27% less time than the comparable levelling survey, which reinstate the fact that the staff-hour cost to conduct an elevation project by GPS was 73% less than by conventional levelling.

A group of researchers from National Geodetic Survey (NGS) United State of America have been actively performing studies to improve the GPS Levelling technique. With the completion of the general adjustment of the North American Vertical Datum of 1988 (NAVD 88), computation of an accurate national high-resolution geoid model (currently GEOID03 with new models under development) (Roman et al. 2004), and publication of NGS' Guidelines for Establishing GPS-Derived Orthometric Heights (Standards: 2 cm and 5 cm) (Zilkoski et al. 2005), GPS-derived orthometric heights can provide a viable alternative to classical geodetic levelling techniques for many applications. Orthometric heights (H) are referenced to an equipotential reference surface, e.g., the geoid. The orthometric height of a point on the Earth's surface is the distance from the geoidal reference surface to the point, measured along the plumb line, normal to the geoid. Ellipsoid heights (h) are referenced to a reference ellipsoid. At the same point on the surface of the earth, the difference between an ellipsoid height and an orthometric height is defined as the geoid height (N).

Several error sources which affect the accuracy of orthometric, ellipsoid, and geoid height values are generally common to neighbouring points. Because these error sources are common, the uncertainty of height differences between nearby points is significantly smaller than the uncertainty of the absolute heights of each point. Adhering to NGS' earlier guidelines, ellipsoid height differences (dh) over short base lines, i.e., not more than 10 km, can now be determined to better than +/- 2 cm (with 2-sigma uncertainty) from GPS phase measurements. Adding in small error for uncertainty of geoid height difference and controlling remaining systematic differences between the three height systems, will typically produce a GPS-derived orthometric height with 2-sigma uncertainties, with +/- 2 cm local accuracy. Geoid height differences can be determined (in selected areas nationwide) with uncertainties that are typically better than 1 cm for distances up to 20 km, and less than 2-3 cm for distances between 20 and 50 km. When using high-accuracy field procedures for precise geodetic levelling, orthometric height differences can be computed with an uncertainty of less than 1 cm over a 50-kilometer distance.

Depending on the accuracy requirements, GPS surveys and current high-resolution geoid models can be used, instead of the classical levelling methods.

Rene Forsberg from Geodynamics Department, Danish National Space Centre is one of the well known figures in geoid determination study. He is also the lead scientist for the Airborne Gravity Survey and Geoid Determination Project for Malaysia in 2003. Summarising the Project (Forsberg, 2005), the geoid fitting is, however, not at the expected accuracy level, which is probably due to occasional errors in levelling and/or GPS data (especially antenna offsets to levelling points are often a source of error). Crustal movements can also play a role if subsidence has occurred between the epochs of levelling and GPS observation. To further improve the Malaysian geoid models he recommends these following actions:

- *Carefully analyze levelling networks, and possibly perform a new adjustment including analysis of subsidence and land uplift (where possible by repeated surveys).*
- *Reanalyze GPS connections and antenna heights at levelling benchmarks.*
- *Resurvey by levelling and GPS of selected, suspected erroneous points with large geoid outliers.*
- *Make a new GPS-fitted version of the gravimetric geoid as new batches of GPS-levelling data become available, and as RTK-GPS users report problem regions for heights.*

1.2 Problem Statement

The geodetic reference frame for Peninsular Malaysia has been realised through the setting-up of the Malaysia Active GPS System (MASS) in 1999. For the vertical reference system, the National Precise Levelling Network (NPLN) was completed in 1998. Peninsular Malaysia used National Geodetic Vertical Datum (NGVD) that was established in 1995 for its height reference.

With steady economic growth in Malaysia since 1998, more expressways, highways, federal and states road have been built or have been widen. The processes have somehow destroyed, damaged or disturbed the benchmark located along the route. Since 2000, DSMM have started to re-survey selected precise levelling route with new planted benchmarks to support survey and mapping industries. Currently the conventional re-surveying processes are quite impractical since the cost is expensive and time consuming.

The purpose of this study is to look into the strategy for rapid height determination using the current GPS technology for height establishment purposes as well as for height monitoring system. The research will involve in analysis of the existing *WMGeoid04* fitted geoid models, refining the *WMGeoid04* with more data and studying the capability of MyRTKnet services of Virtual Reference Station (VRS) in height determination. The process will include data validation, fitting by collocation process and statistical evaluation of the results.

1.3 Research Objectives

The main objectives of this study are:

i. To investigate, analyse and to refine the existing *WMGeoid04* fitted geoid model.

ii. To study the capability of MyRTKnet's Virtual Reference Station (VRS) for height determination.

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1.4 Research Scopes

In order to achieve the research objectives, the scope of works will involve the following procedures:

i. Analyses of *WMGeoid04* fitted geoid model.
ii. To study and analyse the capability of MyRTKnet's VRS for height determination.
iii. Designing of GPS on Benchmark network to refine the *WMGeoid04* fitted geoid model on selected area.
iv. Observations and data processing for GPS project in Putrajaya, Kuala Lumpur, Kluang and Johor Bahru.
v. Geoid fitting by Least Squares Collocation process.
vi. Evaluation, analyses and summarisation.

1.5 Significant of Study

The significances of this study includes:-

i. To study the capability of rapid height determination using the latest technology of GPS and geoid models that can be used by the surveying communities and other public users.

ii. To study, compute and assessment of precise fitted geoid models for Peninsular Malaysia.

iii. Understanding and assessment of Virtual Reference System infrastructure in Malaysia and its technology.

1.6 Research Methodology

Research methodologies will be divided into several stages in order to achieve the objectives of this study. In general, the methodologies are depicted in Figure 1.1.

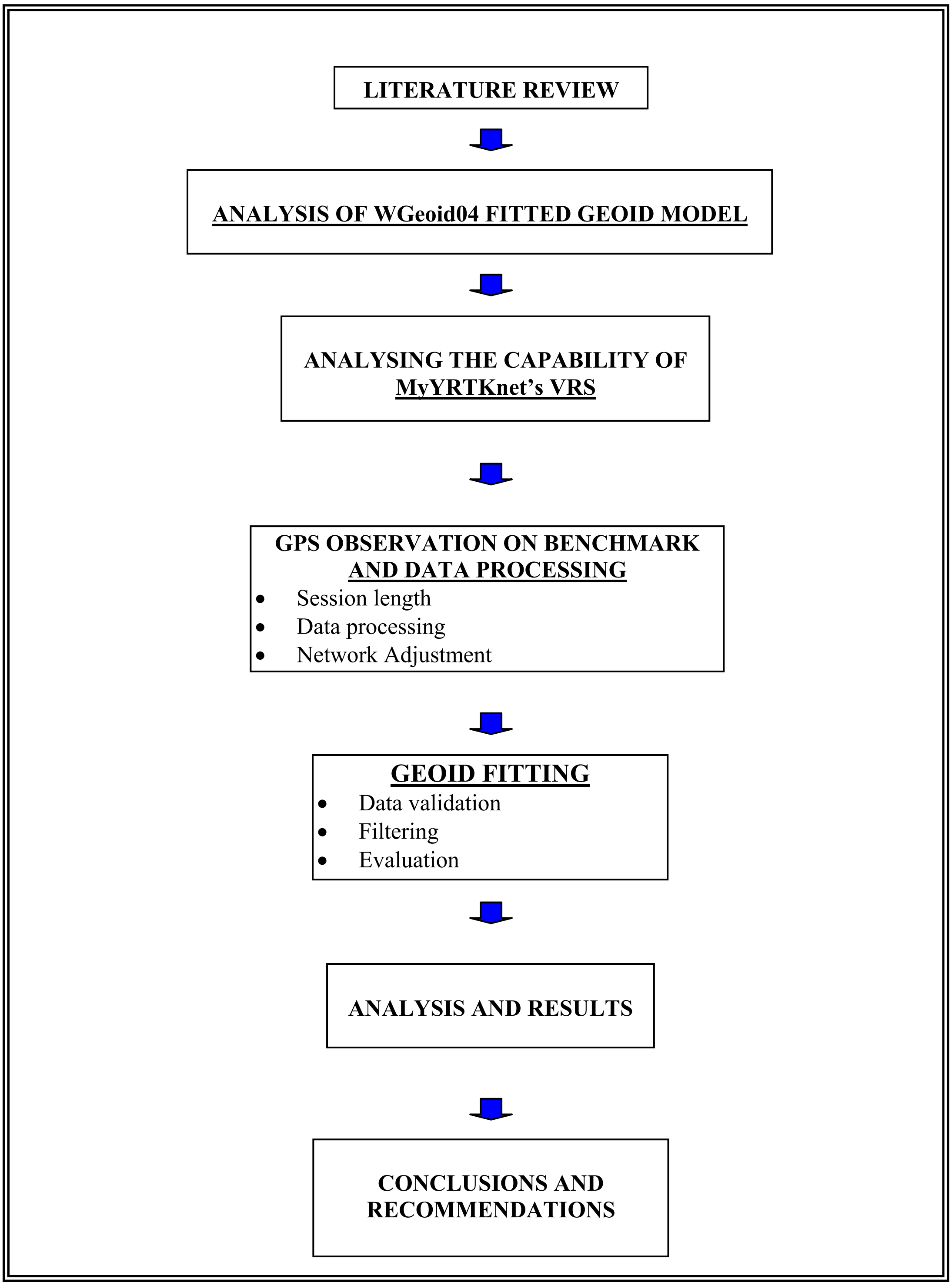

Figure 1.1: Research Methodology

1.7 Chapter's Organisation

This thesis is consists of six (6) chapters. Chapter 1 will mainly discuss on the research background, objectives, scopes, contributions and methodologies. Chapter 2 describes the elements of modern height system and overview of the current geodetic infrastructures in Peninsular Malaysia. Chapter 3 comprises of theoretical aspects of GPS Levelling, Virtual Reference System concept and geoid fitting. Chapter 4 will highlight on analyses of WMGeoid04 fitted geoid models, GPS data processing and adjustment of new GPS on Benchmark Project and analyses of WMGeoid06A revise model. Quality assessments of Virtual Reference Station (VRS) and statistical evaluation of geoid models using VRS are covered in Chapter 5 while conclusions and recommendations are in Chapter 6.