ENHANCEMENT OF DIFFERENTIAL GLOBAL POSITIONING SYSTEM SERVICES IN STRAIT OF MALACCA

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DEDICATION

بسم الله الرحمن الرحيم

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Differential Global Positioning System (DGPS) is a commonly utilised service in maritime activities and safety of navigation supported by Ground-Based Augmentation System (GBAS) and Satellite-Based Augmentation System (SBAS). In 2003, Malaysia established its own GBAS for maritime activities known as *Sistem Pelayaran Satelit* (SISPELSAT), however, some drawbacks persist. Amongst them are the signal coverage limitations, thus, affecting the result of single-base DGPS due to the existing distance-dependent errors. Hence, this study was formulated to enhance the DGPS navigation services through three objectives; firstly, to design suitable locations of DGPS radio beacons along the west coast of Peninsular Malaysia, secondly, to integrate the DGPS radio beacon with satellite communication and, thirdly, to analyse the effect of distance-dependent errors in code-range positioning. The suitability of the location was examined by Global Positioning System (GPS) signal multipath analysis, GPS and MF signal interference investigation, and simulation coverage of the DGPS signal. The SBAS integration was done by transmitting the radio beacon Continuously Operating Reference Station (CORS) data to users by using satellite communication. The output was analysed in terms of signal coverage stability and positioning accuracy and then compared to radio communication. The Wide Area Differential GPS (WADGPS) was developed by using Linear Interpolation Model (LIM) to reduce the de-correlated error in positioning, and the results were compared to Single Point Positioning (SPP) and single-based DGPS accuracy. It was found that the most suitable location for establishing a new SISPELSAT radio beacon was at Padang Mat Sirat, Langkawi, which multipath values for L1 and L2 frequency were 0.38m and 0.42m, respectively. Padang Mat Sirat has fewer GPS and MF signal interference with available station facilities and wide MF signal coverage simulation. Moreover, the result on DGPS by using satellite communication gave good signal coverage of 84.53 percent fix DGPS solution on the coastal area and 93.50 percent on the offshore area. Meanwhile, the accuracy of DGPS by using satellite communication was below 4 meters on the coastal area and below 1.5 meters on the offshore area. In addition, it was found that the WADGPS accuracy was not necessarily better than the DGPS technique or vice versa. Nevertheless, the WADGPS method was reliable in handling the distance-dependent errors with accuracy better than 3 meters while providing extensive service coverage. Therefore, this study concludes that establishing a new radio beacon on a site-specific location, integrating satellite communication and applying the WADGPS provides an alternative option to enhance the Malaysian DGPS navigation services in terms of signal coverage and positional accuracy.

ABSTRAK

Sistem Penentududukan Global Berbeza (DGPS) ialah perkhidmatan yang biasa digunakan dalam aktiviti maritim dan keselamatan pelayaran yang disokong oleh Sistem Augmentasi Berasaskan Darat (GBAS) dan Sistem Augmentasi Berasaskan Satelit (SBAS). Pada tahun 2003, Malaysia menubuhkan GBAS sendiri untuk aktiviti maritim yang dikenali sebagai Sistem Pelayaran Satelit (SISPELSAT), namun beberapa kelemahan masih wujud. Antaranya ialah had liputan isyarat, yang menjejaskan keputusan DGPS asas tunggal disebabkan oleh ralat bergantung jarak yang sedia ada. Oleh itu, kajian ini bertujuan untuk meningkatkan perkhidmatan navigasi DGPS melalui tiga objektif iaitu pertama untuk mereka bentuk lokasi yang sesuai bagi pemancar radio DGPS di sepanjang pantai barat Semenanjung Malaysia, kedua untuk menyepadukan pemancar radio DGPS dengan komunikasi satelit dan, ketiga untuk menganalisis kesan ralat bergantung jarak dalam penentududukan kaedah kod. Kesesuaian lokasi telah diperiksa oleh analisis berbilang laluan isyarat Sistem Penentududukan Global (GPS), penyiasatan gangguan isyarat GPS dan MF, dan liputan simulasi isyarat DGPS. Penyepaduan SBAS dilakukan dengan menghantar data Stesen Rujukan Beroperasi Berterusan (CORS) pemancar radio kepada pengguna dengan menggunakan komunikasi satelit. Dapatan dianalisis dari segi kestabilan liputan isyarat dan ketepatan kedudukan dan kemudian dibandingkan dengan komunikasi radio. Wide Area Differential GPS (WADGPS) telah dibangunkan dengan menggunakan Model Interpolasi Linear (LIM) untuk mengurangkan ralat penyahkorelasi dalam penentududukan, dan hasilnya dibandingkan dengan Penentududukan Titik Tunggal (SPP) dan ketepatan DGPS rujukan tunggal. Didapati lokasi yang paling sesuai untuk mewujudkan pemancar radio SISPELSAT baharu adalah di Padang Mat Sirat, Langkawi yang mempunyai nilai berbilang laluan bagi frekuensi L1 dan L2 masing-masing ialah 0.38m dan 0.42m. Padang Mat Sirat mempunyai lebih sedikit gangguan isyarat GPS dan MF dengan kemudahan stesen yang baik dan simulasi liputan isyarat MF yang luas. Selain itu, keputusan DGPS menggunakan komunikasi satelit memberikan liputan isyarat yang baik iaitu 84.53 peratus penyelesaian DGPS di kawasan pantai dan 93.50 peratus di kawasan luar pesisir. Sementara itu, ketepatan DGPS menggunakan komunikasi satelit adalah di bawah 4 meter di kawasan pantai dan di bawah 1.5 meter di kawasan luar pesisir. Selain itu, didapati ketepatan WADGPS tidak semestinya lebih baik daripada teknik DGPS, begitu juga sebaliknya. Walau bagaimanapun, kaedah WADGPS boleh dipercayai dalam mengendalikan ralat bergantung jarak dengan ketepatan lebih baik daripada 3-meter sambil menyediakan kawasan liputan perkhidmatan yang luas. Oleh itu, kajian ini menyimpulkan bahawa dengan mewujudkan pemancar radio baharu di lokasi khusus, menyepadukan komunikasi satelit dan menggunakan WADGPS boleh menjadi alternatif untuk meningkatkan perkhidmatan navigasi DGPS Malaysia dari segi liputan isyarat dan ketepatan kedudukan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2DRMS	-	Twice Distance Root Mean Square
ASCII	-	American Standard Code for Information Interchange
ASECNA	-	Agency for Aerial Navigation Safety in Africa and Madagascar
BDSBAS	-	BeiDou SBAS
CEP	-	Circular Error Probable
CORS	-	Continuously Operating References Stations
DGPS	-	Differential Global Positioning System
EGNOS	-	European
GAGAN	-	GPS-aided GEO augmented navigation
GBAS	-	Ground Based Augmentation System
GDM2000	-	Geocentric Datum Malaysia 2000
GPS	-	Global Positioning System
IALA	-	International Association of Marine Aids to Navigation and Lighthouse Authorities
IMO	-	International Maritime Organization
KASS	-	Korea Augmentation Satellite System
LIM	-	Linear Interpolation Method
MF	-	Medium Frequency
MSAS	-	MTSAT Satellite Augmentation System
MyRTKnet	-	Malaysia Real-Time Kinematic GNSS Network
NMEA	-	National Marine Electronics Association
NRC-net	-	National Research & Development CORS Network
NTRIP	-	Networked Transport of RTCM via Internet Protocol
PRC	-	Pseudorange Correction
RINEX	-	Receiver Independent Exchange
RTCM	-	Radio Technical Commission for Maritime Services
SACCSA	-	Augmentation System for the Caribbean, Central and South America
SBAS	-	Satellite Based Augmentation System

SDCM	-	System for Differential Corrections and Monitoring
SISPELSAT	-	*Sistem Pelayaran Satelit*
SuGAR	-	Sumatran GPS Array
UTM	-	Universal Transverse Mercator
WAAS	-	Wide Area Augmentation System
WADGPS	-	Wide-Area Differential Global Positioning System
WWRNS	-	World Wide Radio Navigation System

LIST OF SYMBOLS

$P_i^k(t)$	-	Measured code pseudorange from satellite k to station i.
$\rho_i^k(t)$	-	Geometric range between the satellite k and the receiver i.
$\delta_i(t)$	-	Receiver clock error.
$\delta^k(t)$	-	Satellite clock error.
I_i^k	-	Measurement delay due to ionosphere.
T_i^k	-	Measurement delay due to troposphere.
$d^{eph}(t)$	-	Effect of ephemeris error.
$m_i(t)$	-	Multipath.
ε_i^k	-	Pseudorange measurement error.
$\Delta\rho_i^k(t)$	-	Range biases due to radial orbital error and atmospheric. Refraction effects.
$\rho^k(t)$	-	Purely satellite dependent.
$\rho_i(t)$	-	Purely receiver dependent.
$P_i^k(t)$	-	Measured code pseudorange from satellite k to station i.

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia, a fast-growing economic region, has required substantial activities, particularly in marine activities such as navigation, hydrography, fishing industry, harbour fleet-management, and oil and gas exploration. These activities require a reliable augmentation positioning service based on Global Positioning System (GPS). Such a service could be provided by a Differential Global Positioning System (DGPS) technique that can be achieved 1 to 3 meters of positioning accuracy in real-time, hence providing safety of navigation to the user (Zhao, et al., 2016; Gary and Fly, 2008).

Meanwhile, DGPS is one positioning technique recognized by International Maritime Organization (IMO) for World-Wide Radio Navigation System (WWRNS). Furthermore, WWRNS had adopted two types of augmentation systems: Ground Base Augmentation System (GBAS) and Satellite Base Augmentation System (SBAS). The GBAS in DGPS uses a Medium Frequency (MF) radio beacon to transfer the pseudo-range correction (PRC) to the users. Many developed countries have established their MF radio beacon station as an aid in the safety of navigation. Nevertheless, some areas have limited coverage or poor reception of radio beacon signals, for instance, Malacca Straits (Razak, et al., 2018). Hence, additional radio beacon stations could be an alternative in widening the DGPS coverage area. Suitability in terms of reliability, efficiency, and availability of the potential radio beacon station was investigated to give optimum signal coverage on Malacca Straits.

Nevertheless, generated PRC at radio beacon can also be transferred by augmenting satellite communication medium or SBAS. Therefore, DGPS via satellite communication is the latest technology to enhance radio communication for marine navigation. This aligns with the International Association of Marine Aids to

Navigation and Lighthouse Authorities (IALA) recommendation to upgrade radio-based DGPS with satellite communication service (IALA, 2017). Thus, the signal coverage of DGPS correction can be widened by utilizing satellite communication.

DGPS with single base correction has a limitation on distance-dependent error (Bakula, 2010). A previous study by Aris et al. (2015), due to ionospheric delay alone can reach up to 0.5 meters errors for reference to rover stations separation of 274 km in Peninsular Malaysia. Therefore, Wide-Area DGPS (WADGPS) positioning is an alternative to reduce the distance-dependent error, thus enhancing the DGPS positioning accuracy (Bakula, 2010). The distance-dependent effect on DGPS was investigated to prove the efficiency of WADGPS in the safety of navigation.

1.2 Statement of the Problem

The DGPS system that uses MF radio as a data transferring medium has limitation on signal coverage that the signal propagation can only travel up to 250 km (IALA, 2017). Besides that, the MF radio has low availability of communication signals due to poor radio-link coverage. It depends on the line of sight, which means obstructions like mountains, hills, and landmasses can degrade the signal quality (Florence, 2014). Meanwhile, the signal could also deteriorate over time, making some of the crucial areas that were not covered with the PRC (Razak, et al., 2018). Establishment of individual radio beacon and reference station with a good capacity is suggested and reasonable in improving the service continuity, enlarging the signal coverage area, while decreasing the correlation errors (Nejat and Kiamehr, 2013).

The MF radio communication as the current transmitting system is conventional and requires a frequent service with a huge maintenance cost. In addition, there is no backup communication for this DGPS radio navigation system. In order words, the maritime industry in Malacca Straits mainly depends on SISPELSAT for DGPS navigation purposes. This will give a huge drawback if the system faces a failure. Hence, the venture into another alternative, for instance, satellite communication, may benefit the system. IALA also recommends upgrading radio-based DGPS with satellite communication service to improve the availability of navigation activities (IALA, 2017).

Moreover, the DGPS is bound to distance-dependent error, for instance, ionospheric delay, tropospheric delay and radial orbital error (Musa, 2007). In the single reference DGPS positioning, increasing the distance from the reference station reduces the accuracy of the DGPS positioning. Because of the decorrelation of distance-dependent errors, single reference precise DGPS is limited to short distances from the reference station (Nejat and Kiamehr, 2013). Due to the degradation of standard DGPS positioning by these distance-dependent errors, an approach to model these errors by introducing network interpolating method in the positioning is recommended (Ashkenazi et al., 1993; Bakula, 2010; Dai et al., 2003; Gary and Fly, 2008).

1.3 Aim and Objectives

This study aims to enhance the Malaysian DGPS navigation system. The objectives of this study can be defined as follows:

i) To design suitable locations of DGPS radio beacons around the west coast of Peninsular Malaysia.

ii) To integrate the DGPS radio beacon with satellite communication.

iii) To analyse the effect of distance-dependent errors in code-range positioning.

1.4 Scope of the Study

The scopes of this study are given as the following:

i. The study only utilized data from the GPS constellation for positioning, processing and analysing.

ii. Malacca Straits is one of the world's busiest shipping routes, with 100,000 vessels passing through it each year, accounting for about one-quarter of its traded goods (Calamur, 2017). Hence, this research area will be focusing on the shore and coastal area of West Peninsular Malaysia.

iii. The research is collaborating with Malaysia Marine Department and Telekom Malaysia. Hence, designing the new radio beacon stations will consist of radio beacon transmitting stations and monitoring stations at their regulatory area.

iv. This research utilised Thuraya communication satellite to transfer the correction data to the users. This is due to the vast satellite signal coverage which covered the study area, well-known services for the maritime industry (Richharia and Westbrook, 2011), a variety of equipment choices and reasonable service charge by the Thuraya satellite system.

v. The DGPS service by the Marine Department of Malaysia, known as *Sistem Pelayaran Satelit* (SISPELSAT), will be used as the case study in this research. However, along the SISPELSAT, other GPS networks such as National Research & Development CORS Network (NRC-net) and Sumatran GPS Array (SuGAr) network will be used to model the WADGPS correction. This research will use Linear Interpolation Method (LIM) with a post-processing technique.

1.5 Significance of the Study

The significance of this study is described as follows:

i. This study gives a significant advantage for the maritime industry to get a better position, large signal coverage and safety of navigation.

ii. This study can assist the Marine Department of Malaysia to add a new radio beacon station for SISPELSAT stations.

iii. The research can offer multiple communication medium for DGPS positioning to the user.

iv. The single-based DGPS can be enhanced via WADGPS for large coverage while improving the quality of the DGPS correction.

1.6 Research Methodology Approach

In order to achieve the aim and objectives of this study, there are four (4) main phases that have been carried out as illustrated in Figure 1.1:

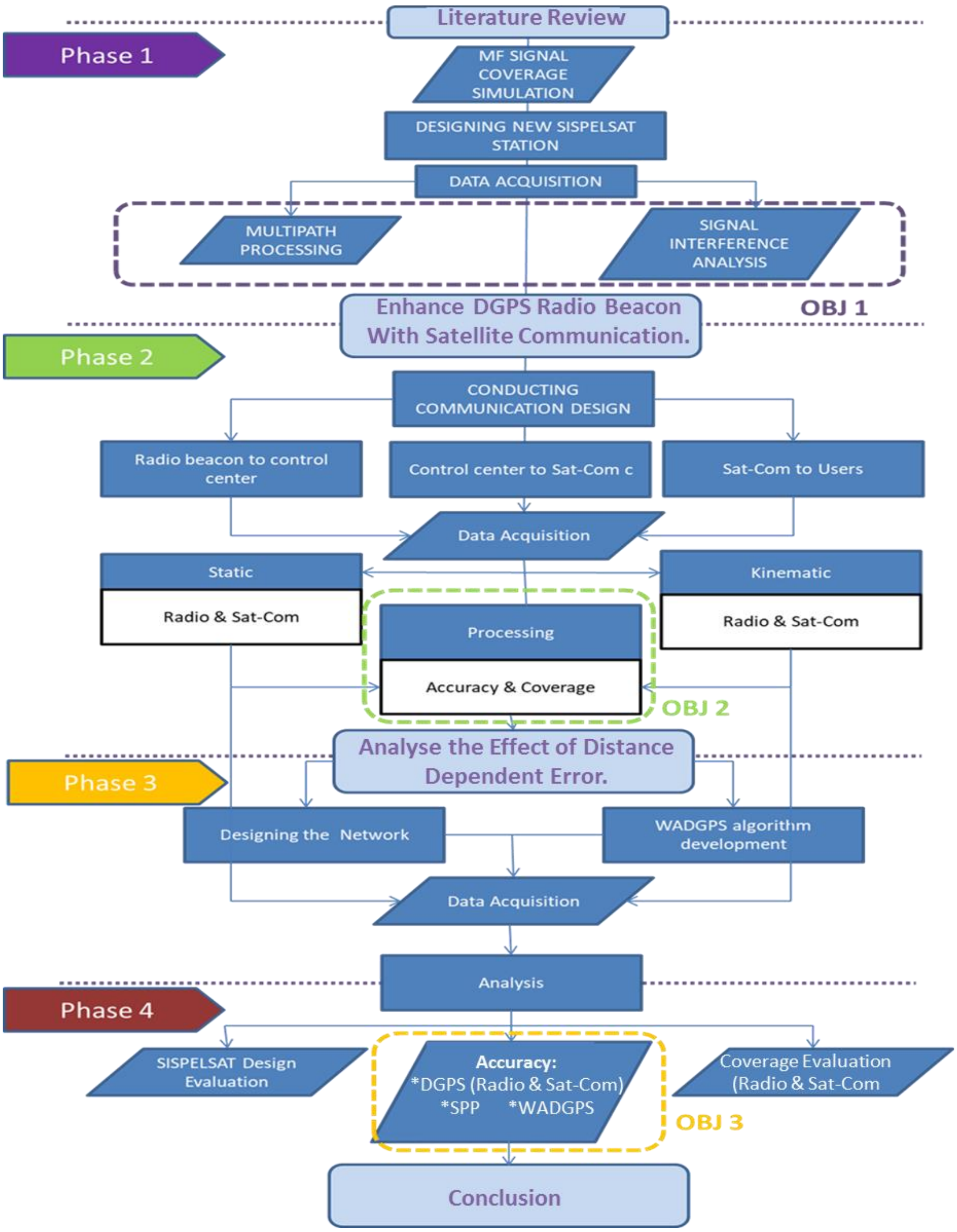

Figure 1.1 The schematic flow of the study.

Phase 1: Designing suitable location of radio beacons around the west coast of Peninsular Malaysia.

- Potential locations were investigated to identify the suitability and compatibility to act as SISPELSAT radio beacon stations.

- Designing the station was needed at the west coast of Peninsular Malaysia to give an optimum MF radio signal coverage in Malacca Straits.
- The first research objective was accomplished upon the completion of this phase.

Phase 2: Enhance the DGPS radio beacon with satellite communication.

- The SISPELSAT station was integrated with the satellite communication system.
- User implementing the GPS SISPELSAT data through satellite communication.
- Comparison of DGPS via radio and satellite communication on accuracy and coverage.
- The second research objective was accomplished upon the completion of this phase.

Phase 3: Analysis of the effect of distance-dependent in code-range positioning.

- Data of Continuously Operating Reference Station (CORS) from National Research CORS network (NRCnet) and Sumatran GPS Array (SuGAr) was downloaded to form a wide-area network covering Malacca Straits.
- Generate PRC network corrections from the network and implement it on rover positioning.
- The post-processed modes were conducted for Single Point Positioning (SPP), DGPS and WADGPS.
- The accuracy of SPP, DGPS and WADGPS were compared to analyse the distance-dependent effect.

Phase 4: Data and Result Analysis.

- The suitability of potential locations for establishing new radio beacon stations was analysed.
- DGPS accuracy and coverage via radio and satellite communication were analysed.
- The accuracy of each technique with a different range of rover stations was presented.
- Results and analysis are presented.
- This phase fulfilled the third research objective.

1.7 Research Structural and Organization

This thesis comprises five (5) chapters explaining the introduction of the research, related literature reviews, workflows and research output in detail. The structure of the thesis is explained as follow:

Chapter 1: Introduction

Chapter 1 provides an overview of the study. The problems were identified, and a clear objective was constructed to give the direction of the study.

Chapter 2: Literature Review

This stage concentrated on reviewing the essential topics, such as the theory of the DGPS techniques and MF signal propagation. The two (2) communication mediums are used to send the correction to the users. This chapter also provides an overview of the WADGPS to enhance the coverage and accuracy of the DGPS navigation system.

Chapter 3: Research Methodology

Chapter 3 describes the research methodology for this research. Each phase plays an important role in enhancing or suggesting the Marine Department of Malaysia to develop SISPELSAT to a better system.

Chapter 4: Result and Discussions

This chapter discusses the design of new DGPS radio beacon stations and the MF signal coverage simulation data validation. Furthermore, this chapter also discusses the efficiency of DGPS via satellite communication compare to radio communication. This chapter also explained the assessments of WADGPS on its accuracy and efficiency on the west coast of Peninsular Malaysia.

Chapter 5: Conclusion and Recommendations

This chapter will summarise the major findings and conclude this study. This chapter also provides recommendations and suggestions for the future outlook.

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