DESIGN AND DEVELOPMENT OF OCEAN MONITORING SYSTEM BASED ON GPS

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DEDICATION

For my beloved family…

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ABSTRACT

Coastal zone of Malaysia has a vital role in socio-economic and environmental in pursuing the country development. However, it constantly faces a threat from coastal erosion. The report year 2013 from the Department of Irrigation and Drainage Malaysia showed 29% of Malaysian coastal has been experiencing erosion at various levels and primarily driven by ocean waves. Hence, this study focused on developing the ocean monitoring system consists of a buoy with Global Positioning System (GPS) technology, reference station and data analysis techniques. The buoy was developed by considering local factors and improves the performance of existing buoy. Comparison with existing GPS buoy has found that the GPS buoy is far exceeded in term of physical specifications, costs, sensors sensitivity and observation interval. Based on the verification with slider machine, this system has been able to provide high accuracy result less than 0.5 cm compared to the standard value of slider machine. The RMS error from data analysis technique is less than 0.0016 m. Validation with Department of Survey and Mapping Malaysia (JUPEM) automatic tide gauges have found both methods agreed on tidal pattern with small discrepancy of less than 10 cm. Encouraging results were also obtained when the observations off coast Senggarang compared with manual observations, historical data and Malaysia Meteorological Department (MetMalaysia) wave forecasting. This system has been observing the same tidal patterns with data analysis RMS error less than 0.0013 m. Comparison with the height of historical wave data and wave forecast shows the results of observations of this system are in the range of comparisons made. Difference of 20 mm was obtained when compared with the wave height observed manually. The usefulness of GPS buoy data also has been demonstrated in analyzing the monsoon wind influences at off coast Senggarang.

ABSTRAK

Persisir pantai Malaysia memainkan peranan yang penting pembangunan Negara samada dalam bidang sosio-ekonomi atau alam sekitar. Walau bagaimanapun ia sentiasa menghadapi ancaman daripada hakisan pantai. Laporan tahun 2013 daripada Jabatan Perparitan dan Saliran Malaysia menyatakan 29% daripada persisir pantai Malaysia telah mengalami hakisan pada berbagai peringkat yang berpunca daripada ombak laut. Oleh itu kajian ini memberi tumpuan kepada pembangunan sistem cerapan lautan yang terdiri daripada boya yang dilengkapi sistem penentududukan sejagat (GPS), stesen rujukan dan teknik analisa data. Perbandingan dengan boya GPS sediada mendapati boya ini jauh lebih baik dari segi fizikal, kos, sensitiviti penderia dan sela cerapan. Berdasarkan verifikasi dengan mesin gelangsar, sistem ini telah dapat memberikan hasil yang berketepatan tinggi iaitu kurang daripada 0.5 cm berbanding nilai piawai mesin gelangsar. Nilai RMS untuk teknik analisa data adalah kurang daripada 0.0016 m. Validasi dengan tolok pasang surut automatik Jabatan Ukur dan Pemetaan Malaysia (JUPEM) mendapati kedua-dua kaedah memberikan corak pasang surut yang sama dengan perbezaan yang kecil kurang daripada 10 cm. Hasil yang memberangsangkan turut diperolehi apabila cerapan di luar persisir pantai Senggarang dibandingkan dengan cerapan secara manual, data arkib dan ramalan ombak Jabatan Meteorologi Malaysia (MetMalaysia). Sistem ini telah mencerap corak pasang surut yang sama dengan nilai RMS teknik analisa data kurang daripada 0.0013 m. Perbandingan ketinggian ombak dengan data arkib dan ramalan ombak mendapati hasil cerapan sistem ini berada dalam lingkungan perbandingan yang dibuat. Ketepatan yang tinggi iaitu 20 mm telah diperolehi apabila perbandingan dengan cerapan ketinggian ombak secara manual dibuat. Kegunaan data boya GPS turut ditunjukkan dalam analisis pengaruh angin monsun terhadap kekuatan ombak di persisir pantai Senggarang.

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LIST OF SYMBOLS AND ABBREVIATIONS

AWAC	-	Acoustic Wave and Current
MDBP	-	Majlis Daerah Batu Pahat
MMD	-	Malaysian Meteorological Department
DID	-	Department of Irrigation and Drainage
NAHRIM	-	National Hydraulic Research Institute of Malaysia
DSMM	-	Department of Survey and Mapping Malaysia
UTHM	-	Universiti Tun Hussein Onn Malaysia
FKAAS	-	Fakulti Kejuruteraan Awam dan Alam Sekitar
L	-	Wave length (horizontal distance between two peaks or in any other point on the waves to the same point in the next wave)
H	-	Wave height (vertical distance from the trough to the crest of same wave)
H	-	Amplitude (H / 2)
G or g	-	Acceleration of gravity
D	-	Water depth from sea bottom
T	-	Wave period (time for a wave length measured from peak to peak)
F	-	Frequency (1/T; number of waves that passes a given point per second)
ρ	-	Density of water (g/cm-3)
E	-	Energy measured in joule per square meter (J/m-2)
V	-	Volume
B	-	Bouyancy

CHAPTER 1

INTRODUCTION

1.1 Background

Ocean is one of the earth's complex physical characteristics yet fully understood by man. The wave, tide and wind are dominant natural external forces in the ocean. A lot of study related to wave, tide and wind has been done to help understand its characteristics, which are advantages for human beings. Accurate forecasts of all these forces are of the utmost importance for the individuals who live, work, or travel on or near the oceans (Pinardi and Woods, 2002). The best decision in the economics or engineering can be made, when the sufficient information has been obtained. The coastal engineering is one of the example of the necessity for prediction of wave. Also, observation data of wave and tide has given useful information to the monitoring of the rise in the sea level, caused by the global warming and mitigation programs for the damaged natural resources.

Ocean has a great influence on Malaysia because most of this country has been surrounded by the ocean, with a total of 4,675 kilometres of coastline, whereby the Peninsular Malaysia has 2068 kilometres, and East Malaysia has 2607 kilometres of coastline. The South China Sea separate two distinct parts of Malaysia from each other. The western part of Peninsular Malaysia is also facing the Strait of Malacca. The coastal zone of Malaysia has a special socio-economic and environmental significance. More than 70% of the population lives within the coastal area and a lot of economic activities such as urbanization, agriculture, recreation and eco-tourism, fisheries, aquaculture and oil and gas exploration are situated in the area. Within

these coastal areas, the industrialization and development demands had a great influence on the resources and coastline itself, with a large percentage of population living within 5 km from these areas. The zoning plans with multiple usages exist only in the framework of concrete management, i.e. the coastal and marine protected areas (Agardy, 1993). Generally, the coastal zone plays a vital role in the development of the country; however, it constantly faces a threat from erosion.

The National Coast Erosion Study, which began in 1984 and completed by 1986 was the first comprehensive study carried out to assess the shoreline of Malaysia. It has been reported by the study that 52% of the coastline in the east coast of Peninsular Malaysia is being eroded, 43% is stable, 1% is rebuilding and 4% undergoes changes according to the seasons. In the west coast, 50% of the coastline is being eroded, 30% is stable and 20% is rebuilding (Ghazali, 2006). An eroding coastline is considered critical if the structures within the area are in immediate danger, whilst it is deemed significant if the erosion is going to endanger the structures within the five years without any coastal protection. An eroding shoreline is deemed acceptable if the backshore area is uninhabited. The economic value of the development of backshore area and the physical rate of erosion are considered as the primary factors to determine the category of shoreline. The latest study has revealed that about 29% of the total of 4,800 km of Malaysian shoreline was subjected to the varying degree of erosion (Department of Irrigation and Drainage Malaysia, 2013).

Coastal erosion is a natural phenomenon, which results from the interactions between natural process and the system. The natural process is primarily responsible for coastal erosion and it is driven by waves (Inch, 2014). Although erosion is mainly contributed by waves action, our knowledge on this factor is still far from sufficient. This occurs because of the shortage of data, coverage is not comprehensive and observation techniques are not efficient.

In most of the countries, it has been observed that the most appropriate coastal and shoreline data in Malaysia are currently collected by many government departments, private sector organization, scientists and consultants. Moreover, except for the data regarding tidal elevation and shore-based wind, data on other important parameters such as waves and currents are hardly collected if available; the collection programme is tailored to a specific with a short term duration (Bernatchez and Dubois, 2008).

Because the availability of ocean tidal and wave height data for Malaysian ocean is not comprehensive, new effort to collect wave data must be made. Tidal data can only be obtained in certain places if there is Department of Survey and Mapping Malaysia (JUPEM) tidal observation stations located. While the wave height data supplied by Malaysian Meteorological Department (MET) was obtained from volunteering ship observations that sail through our waters. Since it is from the commercial ship, data is less comprehensive because normal for commercial ships to choose a same route and will only change the route in case of bad weather.

Ocean wave measurement from satellite combined with global wave and atmospheric numerical models are dramatically changing our way of obtaining ocean wave data for engineering purposes. Remote sensing satellite observations are now at the point of providing reliable global long-term wave statistics. A direct sea state observation is straightforward; however, the usual observations from ships in the transit are not adequate enough to provide the reliable data (Campbell and Wynne, 2011).

Although the remote sensing satellite is capable of providing imagery for the wave characteristics extraction process, however it is not an absolute solution for the measurement of ocean waves. This remote sensing satellite is still restricted and fixed to its repetition orbit. As a solution, the satellite of Global Positioning System (GPS) provides an ultimate solution due to its numerous numbers, which contributes to the flexible observation and unlimited coverage (Kaplan and Hegarathy, 2005). The GPS satellite has been used for wave observation globally by many researchers such as Yang and Lo (2000), Chang and Sun (2004), Harigae et al. (2005), Daud et al. (2008) and Cui and Kouguchi (2011). Hence, this study will be focusing on GPS wave buoy system development.

1.2 Problem statement

Ocean wave data in Malaysia are currently collected by many government agencies, private sector organization, scientists and consultants. The government agencies are Malaysian Meteorological Department, Department of Survey and Mapping Malaysia, Royal Navy Malaysia, Department of Irrigation and Drainage (DID) and Marine Department Malaysia. Although there are many parties involve, the wave data are still insufficient because the present observations do not cover all Malaysian

water, subject to observations by third parties and conventional observation methods used (Yaakob et al., 2004).

Problem of data coverage is due to the type of equipment used. The equipment used is categorized as fix type equipment makes the process of relocation to the area of interest is impossible to do. Although the equipment is capable of providing a high accuracy data but it covers only a particular area where the equipment is installed. An example is the JUPEM automatic tide gauge. This equipment has been installed in 22 national tidal gauge telemetry stations throughout Malaysia (JUPEM, 2016). Tidal data to all these areas is available but other areas like Batu Pahat where there is no observation stations nearby, alternative method for wave observation should be considered to address this issue. Users also do not get the high accuracy data. For example, the JUPEM tidal data that can be obtained only in hourly intervals. Moreover, data on other important parameters such as waves and currents are hardly collected if available; the collection programme is tailored to a specific with a short term duration (Bernatchez and Dubois, 2008).

Data collection also depends on the observations by third parties, examples are waves data which was provided by MET. The wave data were observed by voluntary commercial ship that sailed through the water of this country. This data only covers the water around the shipping lane at a certain period of time. Users are unable to request for wave data for certain area and time. Given these data obtained from voluntary commercial ship, the accuracy is also questionable.

Methods of data observation using conventional equipment also contributed to this problem. The conventional observation of the wave or tide is performed by using the fixed type observation equipment which was equipped with water pressure sensor, ultrasonic sensor or accelerometer (Nagai et al., 2005). This sensors are very sensitive and require delicate handling. In order to get high accuracy data it needs periodical calibration and maintenance, which involves high costs. In addition, this equipment is also difficult to be relocated to other locations.

Researchers have taken actions to overcome this issue through their personal wave observation. Muzathik et al. (2011) has deployed an Acoustic Wave and Current (AWAC) device to observe the characteristics of waves along the Terengganu coast. Although the equipment managed to observe the wave characteristics of waves, but it requires carefully checking and validation of the instrument to ensure the accuracy of the collected data. Validation and maintainance

of this equipment is very costly. In addition, this equipment is difficult to install and need highly skilled individuals. The equipment is considered as a fix type equipment and relocation process is difficult.

Taira et al. (1996) used the electromagnetic current meter and acoustic sensors to observe oceanographic data off the Kuala Terengganu coast. Although the equipment is capable of observing the relevant data, it requires a large ship for deployment. The periodic calibration is a must as the equipment have sensitive sensors. Although the equipment is categorized as transferable but the process is costly.

Marghany (2000) had used ERS-l and AIRSAR/TOPSAR data to extract wave spectra to predict the alterations in shoreline on the basis of wave refraction and sediment transport. Although this technique can be used to extract the wave spectra for modelling of the alterations in shoreline, but still the assistance is required for verification from other data sources such as ship observation, ground truth data and aerial photography. Any imperfection of supporting data will influenced the generated waves data. Since this method still requires other supporting data before the waves information is obtained makes it not a practical solution.

Methods that have been mentioned before is not a comprehensive solution to the problem of wave observation in Malaysia. Practical solutions which able to meet the needs of many parties and suitable to the country's waters condition must be produced to address this issue. Presently, the GPS technology provides the best solution to overcome this problem. The new buoy type observation equipment adapting GPS technology has excellent features of sea level and wave propagation measurement systems, as proposed by different researchers around the world such as Doong et al. (2011), Waseda et al. (2014), Cheng et al. (2008) and Collins et al. (2014). It is capable of providing the function that the fluctuation of sea surface of a broad frequency band can be observed in the accuracy of several centimeter continuously (Dawidowicz, 2014). The principles, functions and accuracy of the system are also reported by Joodaki et al. (2013), Nagai et al. (2003), Terada et al. (2003), Ohta et al. (2006) and Daud et al. (2008).

Hence, this study focuses on developing an ocean monitoring system consisting of a buoy equiped with high precision GPS receiver, high precision reference station and data analysis techniques which is suitable for the Malaysian coastal area especially for the Straits of Malacca.

1.3 Aim and objectives

To overcome the short comings of the wave observation in Malaysia and its lack of data coverage, its accuracy and out-dated techniques, therefore the aim of this study is to develop an ocean monitoring system which utilises the GPS technology.

To achieve these aim, the specific objectives of this research are:

i) To design, fabricate and test the stability of the ocean monitoring system

ii) To verify the data analysis technique and validate the GPS buoy measurement

iii) To analyze the effect of tidal wave and monsoon wind on wave energy

1.4 Scope of the study

The scopes of this study can be divided and described in the following aspects:

i) Study area

The area of study chosen is the coastal of Senggarang, Batu Pahat, Johor. The area is selected because it has experienced severe erosion where the destruction of property, coastal areas and agricultural areas have occurred (Utusan Malaysia, 2012). Further, it is a high populated and rapid development area. Aim of this study is to develop GPS buoy to measure high accuracy tidal and wave height data for this area. Hopefully the data provided able to help the responsible authorities to understand the wave characteristics and solve the erosion problems within this area.

ii) Strait of Malacca wind and wave historical data

The Strait of Malacca wind and wave historical data from 2010 to 2012 has been obtained from Malaysian Meteorological Department. The analysis from this data is one of the critical inputs, which should be necessarily considered during the designing process of the GPS buoy.

iii) Wave simulator (slider machine)

The slider machine is capable of replicating the movement of buoy constantly for a long period. This machine is very helpful in verification, validation and understanding process throughout this study. The GPS antenna was put on the slider machine and it constantly keeps on rotating during the observation. The observation data were compared with the standard data to verify and validate the data analysis techniques and equipment of this study.

iv) GPS buoy

The designing of GPS buoy has been performed by considering the wind wave historical data, buoy buoyancy, roll and heave factors, weight and water proofing. The fabrication process and choosing the most appropriate material were carefully done to ensure the lasting usage and cheap.

v) Reference station

The reference station is very important in the observations of GPS, as it is the point of reference to all the fieldwork campaign in this study. A data of high accuracy can be obtained only if the reference station is stable and capable of receiving the GPS satellite signals of high quality.

vi) Wave observation

The wave observation was performed four times, during three different monsoons. This observation was continuous for 30 hours with data logging rate of 1 Hz. During the GPS buoy observation, the manual observation of wave height and tidal were also done for the purpose of data comparison.

vii) Tidal data

The tidal data of JUPEM was used to validate the tidal data observed by using the GPS buoy. The JUPEM data is reliable because this department is responsible of providing the entire tidal data in Malaysia for public and private usage. It was collected by automatic fix tide gauge at several locations in the whole Malaysia.

viii) Data analysis techniques and programming

Development of data analysis techniques and programming was done by using Bernese 5.0 and MATLAB software.

1.5 Significance of study

This study is of significant importance because of its major contribution to several parties such as local authorities, government agencies and private sectors. Furthermore, it also provides low cost, effective and precise solution to measure the wave characteristics. The government agencies such as Malaysian Meteorological Department, Department of Irrigation and Drainage (DID) and National Hydraulic Research Institute of Malaysia (NAHRIM) will hugely benefit from this study. Hopefully it will help the responsible agencies to identified the coastal area

REFERENCES

Abidin, H. Z. (1999). Monitoring Sea Level Using GPS. *Proceeding of the International Seminar on Application of Seawatch Indonesia Information System for Indonesian Marine Resources Development*, Jakarta, Indonesia.

Agardy, M. T. (1993). Accommodating ecotourism in multiple use planning of coastal and marine protected areas. *Ocean & Coastal Management*, 20(3), 219-239.

Arroyo-Suarez, E. N., Hsiao, V. & Mabey, L. D. L. (2005). Implementation of a positioning and telemetry buoy to determine chart datum for hydrographic survey applications. In *OCEANS, 2005. Proceedings of MTS/IEEE* (pp. 1726-1728). IEEE.

Bender, L. C., Guinaso Jr, N. L., Walpert, J. N. & S. D. Howden. (2010a). A comparison of methods for determining significant wave heights - Applied to a 3-m discus buoy during hurricane Katrina. *Journal of Atmospheric and Oceanic Technology*, 27, 1012 – 1018.

Bender, L. C., Howden, S. D., Dodd, D. & Guinasso, N. L. (2010). Wave Heights during Hurrincane Katrina: An Evaluation of PPP and PPK Measurements of the Vertical Displacement of the GPS Antenna. *Journal Atmospheric and Oceanic Technology*, 27, 1760 – 1768.

Bernatchez, P. & Dubois, J. M. M. (2008). Seasonal quantification of coastal processes and cliff erosion on fine sediment shorelines in a cold temperate climate, north shore of the St. Lawrence maritime estuary, Québec. *Journal of Coastal Research*, 24(1), 169 - 180.

Bhatta, B. (2010). *Global Navigation Satellite Systems: Insights into GPS, GLONASS, Galileo, Compass, and Others*. BS Publications.

Bonnefond, P., Exertier,P., Laurain, O., Menard, Y., Orsoni, A., Jan, G. & Jeansou, E. (2003). Absolute calibration of Jason-1 Topex/Poseidon altimeters in Corsica. *Marine Geodesy*, 26, 261 – 284.

Born, G. H., Parke, M. E., Axelrad, P., Gold, K. L., Johnson, J., Key, K. W. & Kubitschek, D. G. (1994). Calibration of TOPEX altimeter using GPS buoy. *Journal of Geophysical Research*, 99(C12), 24517 – 24526.

Bouin, M. N., Ballu, V., Calmant, S., Cheng, K., Shum, C. & Testut, L. (2003). Absolute height of sea surface by trajectory of GPS antennae over submerged pressure gauges. *Presented at the AGU Fall Meeting*, San Francisco, California, United State America.

Buble, G., Bennett, R. A. & Hreinsdottri, S. (2010). Tide gauge and GPS measurements of crustal motion and sea level rise along the eastern margin of Adriatic. *Journal of Geophysical Research*, 115(B2).

Campbell, J. B. & Wynne, R. H. (2011). *Introduction to remote sensing*. New York, United State America: Guilford Press.

CDIP, (2015). Wave dynamics. Available online at http://cdip.ucsd.edu/. Retreived on 15.12.2015.

Chai, T. & Draxler, R. R. (2014). Root mean square error (RMSE) or mean absolute error (MAE) – Arguments against avoiding RMSE in the literature. *Geoscientific Model Development*, 7, 1247 – 1250.

Chang, C. C,, Lee, H. W. & Tsui, I. F. (2002). Preliminary test of tide independent bathymetric measurement based on GPS. *Geomatics Research Australasis*, 76, 23-36.

Chang, C. C. & Sun, Y.D. (2004). Application of a GPS-Based Method to Tidal Datum Transfer. *The Hydrographic Journal*, 112, 15 – 20.

Chen, W., Hu, C., Li, Z., Chen, Y., Ding, X., Gao, S. & Ji, S. (2004). Kinematic GPS Precise Point Positioning for Sea Level Monitoring with GPS Buoy. *Journal of Global Positioning Systems*, 3(1-2), 302 – 307.

Cheng, K., Shum, C., Han, C., Yi, Y. & Martin, D. (2001). Application of GPS-buoy water level instrument for radar altimeter calibration. Proceeding of the Gravity, Geoid and Geodynamics 2000: GGG2000 IAG International Symposium, Berlin.

Cheng, K. C., Kuo, C. Y., Shum, C. K. & NIU, X. R. (2008). Accurate linking of Lake Erie water level with shoreline datum using GPS buoy and satellite altimetry. *Terrestrial, Atmospheric and Oceanic Sciences*, 19, 53 – 62.

Cheng, K. C., Calmant, S., Kuo, C. Y., Tseng, H. Z., Shum, C. K., Seyler, F. & Silva, J. S. D. (2009). Branco river stage gradient determination and Amazon hydrologic studies using GPS Water level measurements. Marine Geodesy, 32, 267 – 283.

Chia, C. C. & Yuan, D. S. (2004). Application of a GPS based method to tidal datum transfer. *Hydrographic Journal*, 112, 15 – 20.

Chiang, E. P., Zainal, Z. A., Narayana, P. A. A. & Seetharamu, K. N. (2003). Potential of renewable wave and offshore wind energy sources in Malaysia. *Proceedings of the International Symposium on Renewable Energy: Environment Protection & Energy Soilltion for Sustainable Development*, Kuala Lumpur, Malaysia.

Christensen, E. J., Haines, B. J., Keihm, S. J., Morris, C. S., Norman, R. A., Purcell, G. H., Williams, B. G., Wilson, B. D., Born, G. H., Parke, M. E., Gill, S. K., Shum, C. K., Tapley, B. D., Kolenkiewicz, R. & Nerem, R. S. (1994). Calibration of TOPEX/POSEIDON at Platform Harvest. *Journal of Geophysical Research*, 99(C12), 24465 – 24485.

Collins, C. O., Lund, B., Waseda, T. & Graber, H.C. (2014). On recording sea surface elevation with accelerometer buoys: lessons from ITOP (2010). *Ocean Dynamic*, 64(6), 895 – 904.

Cui, J. & Kouguchi, N. (2011). Ocean Wave Observation by GPS Signal. Paper presented at IEEE Oceanic Engineering Society. Santander, Spain.

Dach, R., Hugentobler, U., Fridez, P. & Meindl, M. (2007). User manual of the Bernese GPS Software Version 5.0. Astronomical Institute, University of Bern.

Datawell, (2014). Datawell Waverider Reference Manual (WR-SG, DWR-MkIII, DWR-G). Retreived on November 18, 2014 from http://download.datawell.nl/documentation/datawell_manual_dwr-mk3_dwrg_wr-sg_2010–07–28.pdf.

Daud, M. E., Sagiya, T., Kimata, F. & Kato, T. (2008). Long-baseline quasi-real time kinematic GPS data analysis for early tsunami warning. *Earth Planet Space*, 60, 1191 – 1195.

Dawidowicz, K. (2014). Sea level changes monitoring using GNSS technology – a review of recent efforts. *Acta Adriatica*, 55(2), 145 – 162.

Dawod, G. M. & Abdel-Aziz, T. M. (2003). Establishment of a precise geodetic control network for updating the River Nile maps. Proceedings of Al-Azhar Engineering 7th International Conference, Cairo, Mesir.

Dean, R. G. & Dalrymple, R. A. (2004). *Coastal processes with engineering applications*. United Kingdom: Cambridge University Press.

Department of Irrigation & Drainage Malaysia. (2013). *Coastal Management*. Available on line at http://www.water.gov.my. Retrieved 24 August 2014.

Dewar, P. & Hannah, J. (2005). An Assessment of the Accuracy of Three Tidal Datum Transfer Procedures in a Harbour Environment. *The Hydrographic Journal*, 117, 3 – 7.

Doong, D. J., Lee, B. C. & Kao, C. C. (2011). Wave Measurements Using GPS Velocity Signals. *Sensors*, 11, 1043 – 1058.

Douglas, B., Kearney, M. T. & Leatherman, S. P. (Eds.). (2001). *Sea level rise: History and consequences*. California, United State America: Academic Press.

Dow, J. M., Neilan, R. E. & Rizos, C. (2009). The International GNSS Service in a changing landscape of Global Navigation Satellite Systems. Journal Geodesy, 83, 191 – 198.

Dunne, S., Soulat, F., Caparrini, M., Germain, O., Farres, E., Barroso, X. & Ruffini, G. (2005, June). Oceanpal/sup/spl reg//a GPS-reflection coastal instrument to monitor tide and sea-state. In *Oceans 2005-Europe* (Vol. 2, pp. 1351-1356). IEEE.

El-Rabbany, A. (2006). Introduction to GPS: The Global Positioning System. Massachusetts, United State America: Artech House Publishers.

Envirtech, (2014). Envirtech MKI-3: Directional – ODAS – MAWS. Retreived on November 18, 2014, from http://www.envirtech.hk/index.html.

Envirtech, (2015). MKI-4 Envirtech Easy to Deploy Tsunami Buoy. Retreived on May 13, 2015, from http://www.envirtech.com/docs/MKI-4.pdf.

Florida Center for Instructional Technology, (2005). Beach Profiles – Response to Oceanic Conditions. Retreived on January 20, 2016, from http://fcit.usf.edu/florida/teacher/science/mod2/beach.profiles.html

Fowler, C. M. R. (1990). *The solid earth: an introduction to global geophysics*. United Kingdom: Cambridge University Press.

Fugro, (2012). Fugro Launches Seawatch Wind Lidar Buot at Global Offshore Wind. Retreived on November 18, 2014, from http://www.oceanor.no/newsroom/News_overview_2012/Lidar.

Gesch, D. & Wilson, R. (2001). Development of a seamless multisource topographic bathymetric elevation model of Tampa Bay. *Marine Technology Society Journal*, 35(4), 58 – 64.

Ghazali, N. H. M. (2006). Coastal erosion and reclamation in Malaysia. *Aquatic Ecosystem Health & Management*, 9(2): 237 – 246.

Goring, D. (2007). Transferring a Survey Datum Across Water. Mulgor Consulting Ltd., Christchurch. Retrieved on February 24, 2015 from http://www.tideman.co.nz/SurveyDatums/, Retreived on 1st October 2014.

Grebenitcharsky, R. S., Rangelova, E. V. & Sideris, M. G. (2005). Transformation between gravimetric and GPS/levelling-derived geoids using additional gravity information. *Journal of Geodynamics*, 39, 527 – 544.

Gulev, S. K., Grigorieva, V., Sterl, A. & Woolf, D. (2002). Global-scale wave observations from voluntary observing ships: Assessment of reliability and potentialities for global and off-shore regions studies. In *Proceedings of the 7th international workshop on wave hindcasting and forecasting* (p. 11).

Haines, B., Bonnefond, P., Born, G., Exertier, P., Gill, S., Jeansou, E., Kubitschek, D., Jan, G., Laurain, O., Menard, Y. & Orson, A. (2002). Calibrating the JASON-1 measurement system: Initial results from the Corsica and Harvest verification experiments. *Presented at the AGU Fall Meeting*, San Francisco, California, United State America.

Harigae, M., Yamaguchi, I., Kasai, T., Igawa, H., Nakanishi, H., Murayama, T. & Suko, H. (2005). Abreast of the waves: Open-sea sensor to measure height and direction. *GPS World*, *16*(5).

He, Y., Shen, H. & Perrie, W. (2006). Remote Sensing of Ocean Waves by Polarimetric SAR. *Journal of Atmospheric and Oceanic Technology*, 23, 1768 – 1773.

Hein, G. W., Landau, H. & Blomenhofer, H. (1990). Determination of instantaneous sea surface wave heights and ocean currents using satellite

observations of the Global Positioning System. *Marine Geodesy*, 14, 217 – 224.

Herbers, T. H. C., Jessen, P. F., Janssen, T. T., Colbert, D. B. & MacMahn, J. H. (2012). Observing ocean surface waves with GPS-tracked buoys. *Journal of Atmospheric and Oceanic Technology*, 29, 944–959.

Hess, K. W. (2001). *Generation of Tidal Datum Fields for Tampa Bay and the New York Bight. US Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, Maryland*. NOAA Technical Report NOS CS 11.

Hessner, K., Reichert, K., Dittmer, J., Borge, J. C. N. & Günther, H. (2001). Evaluation of WaMoS II wave data. In *Ocean Wave Measurement and Analysis* (pp. 221-230). ASCE.

Hocker, B. & Wardwell, N. (2001). Tidal datum determination and VDatum evaluation with a GNSS Buoy. In Proceedings of the 23rd International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2010) (pp. 2076-2086).

Hofmann-Wellenhof, B., Lichtenegger, H. & Wasle, E. (2007). *GNSS–global navigation satellite systems: GPS, GLONASS, Galileo, and more*. Berlin, Heidelberg: Springer Science & Business Media.

Holthuijsen, L. H. (2007). *Waves in oceanic and coastal waters*. United Kingdom: Cambridge University Press.

Hong, J., Back, K., Park, U., Lee, D. & Cha, S. (2008). Determination of ocean datum using GPS buoy observation data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 37, 685 – 688.

Hou, D., Hamada, M., Yoo, Y. J. & Kouguchi, N. (2007). Evaluation test result on wave direction measurement using GPS buoy. In OCEANS 2006-Asia Pacific (pp. 1-5). IEEE.

Inch, K. W. (2014). *Surf Zone Hydrodynamics: Measuring Waves and Currents.* Retrieved on December 12, 2014 from http://www.geomorphology.org.uk/sites/default/files/geom_tech_chapters/3.2.3_SurfZoneHydrodynamics.pdf.

Jeans, G., Bellamy, I., Vries, J. J. & Weert, P. V. (2003) Sea Trial of the New Datawell GPS Directional Waverider. *Proceedings of the IEEE/OES Seventh Working Conference*, 145 – 147.

Johnson, D., Stocker, R., Head, R., Imberger, J. & Pattiaratchi, C. (2003). A compact, low-cost GPS drifter for use in the oceanic nearshore zone, lakes, and estuaries. *Journal of Atmospheric Oceanic Technology*, 20, 1880 – 1884.

Joodaki, G., Nahavandchi, H. & Cheng, K. (2013). Ocean Wave Measurement Using GPS Buoys. *Journal of Geodetic Science*, 3(3), 163 – 172.

JUPEM. (2000). Circular of the Director General of Survey and Mapping. – "Not published".

JUPEM, (2002). Pekeliling Ketua Pengarah Ukur dan Pemetaan Malaysia. Bil. 5.

JUPEM, (2005). Pekeliling Ketua Pengarah Ukur dan Pemetaan Malaysia. Bil. 10.

JUPEM, (2016). Data Air Pasang Surut. Retreived on July 24, 2014 from https://www.jupem.gov.my/v1/my/produk-perkhidmatan/data-air-pasang-surut/.

Kaihatu, J. M., Veeramony, J., Edwards, K. L. & Kirby, J. T. (2007). Asymptotic behavior of frequency and wave number spectra of nearshore shoaling and breaking waves. *Journal of Geophysical Research: Oceans, 112*(C6).

Kaplan, E., & Hegarty, C. (Eds.). (2005). *Understanding GPS: principles and applications*. Massachusetts, United State America: Artech House Publishers.

Karimpour, A. (2015). *Oceanlyz: Ocean wave analyzing toolbox*. MATLAB Toolbox Version 1.3: User manual.

Kato, T., Terada, Y., Ito, K., Hattori, R., Abe, T., Miyake, T., Ko-shimura, S. & Nagai, T. (2005). Tsunami due to the 2004 Sep-tember 5th off the Kii peninsula earthquake, Japan, recorded by a new GPS buoy. *Earth Planets Space*, 57, 297 – 301.

Kato, T., Terada, Y., Kinoshita, M. & Kakimoto, H. (2000). Real-time observation of tsunami by RTK-GPS. *Earth Planets and Space*, 52 (10), 841 – 846.

Kato, T., Terada, Y., Kinoshita, M., Kakimoto, H., Isshiki, H. & Moriguchi, T. (2001). A new tsunami monitoring system using RTK-GPS. *Proceeding of the US National Tsunami Hazard Mitigation Program Review and International Tsunami Symposium*, 7 – 10.

Kato, T., Terada, Y., Nagai, T. & Koshimura, S. (2010). Tsunami Monitoring System Using GPS Buoy – Present Status and Outlook. *IEEE Geoscience and Remote Sensing Symposium*, 65(4), 3043 – 3046.

Kavanagh, B. F. (2006). *Surveying : Principles and Applications*. 7th ed. New Jersey, United State America: Pearson Prentice Hall.

Kendall, M. G., Stuart, A. & Ord, J. K. (1987). Kendall's Advanced Theory of Statistics, Vol. 1: Distribution Theory. 6th ed. New York: Oxford University Press.

Kenney, J. F. & Keeping, E. S. (1962). Mathematics of Statistics. 3rd ed. Princeton, New Jersey: Van Nostrand.

Key, K., Parke, M. & Born, G. (1998). Mapping the sea surface using GPS buoy. *Marine Geodesy*, 21, 67 – 79.

Kotsakis, C. (2008). Transforming ellipsoidal heights and geoid undulations between different geodetic reference frames. *Journal of Geodesy*, *82*(4-5), 249-260.

Kouba, J. & Heroux, P. (2001). Precise Point Positioning Using IGS orbit and Clock Products. *GPS Solutions*, 5(2), 12 – 28.

Krogstad, H. E., Barstow, S. F., Aasen, S. E. & Rodriguez, I. (1999). Some recent developments in wave buoy measurement technology. *Journal of Coastal Engineering*, 37(3–4), 309–329.

Kruizinga, G. L. H. (1997). *Validation and applications of satellite radar altimetry*. University of Texas at Austin.

Larson, K. M., Lofgren, J. S. & Rudiger. (2013). Coastal sea level measurements using a single geodetic GPS receiver. *Advances in Space Research Journal*, 51(8), 1301 – 1310.

Lee, K. S. & Seng, L. Y. (2009). Simulation Studies on the Electrical Power Potential Harnessed by Tidal Current Turbines. *Journal of Energy and Environment*, 1(1), 18 – 23.

Lehner, S., Schulz-Stellenfleth, J., Schättler, J. B. H., Breit, H. & Horstmann, J. (2000). Wind and wave measurements using complex ERS-2 wave mode data. *IEEE Transactions on Geoscience and Remote Sensing*, 38(5), 2246 – 2257.

Leick, A., Rapoport, L. & Tatarnikov, D. (2015). *GPS satellite surveying*. New Jersey, United State America: John Wiley & Sons.

Li, R., Bedford, K., Shum, C. K., Niu, X., Zhou, F., Velissariou, V. & Zhang, A. (2006). Digitalization of coastal management and decision making supported by multi-dimensional geospatial information and analysis. In *Proceedings of the 2006 international conference on Digital government research* (pp. 429-430). Digital Government Society of North America.

Liebsch, G., Novotny, K. & Dietrich, R. (2002). Comparison of multimission altimetric sea surface heights with tide gauge observations in the Southern Baltic Sea. *Marine Geodesy*, 25, 213 – 234.

Lighthill, M. J. (1962). Physical interpretation of the mathematical theory of wave generation by wind. *Journal of Fluid* Mechanics, 14(2), 385 – 398.

MacMahan, J., Brown, J. & Thornton, E. (2009). Low-cost handheld Global Positioning System for measuring surf-zone currents. *Journal of Coastal Research*, 25 (3), 744 – 754.

Marghany, M. M. (2000). Wave spectra and shoreline changes studies by remote sensing. Universiti Putra Malaysia: PhD Thesis.

Marshall, A. & Denys, P. (2009). Water level measurement and tidal datum transfer using high rate GPS buoys. *New Zealand Surveyor*, (299), 24.

McDonnell, M. J. (1981). Box-filtering techniques. *Computer Graphics and Image Processing*, 17(1), 65 – 70.

Misra, P. & Enge, P. (2006). *Global Positioning System: Signals, Measurements and Performance*. 2nd ed. Lincoln, Massachusetts, United State America: Ganga Jamuna Press.

MET, (2014). Wave forecasting for Malaysia. Retrieved on April 14, 2015, from http://www.met.gov.my/web/metmalaysia/forecast/marine/wavewindcharts.

Muzathik, A. M., Wan Nik, W. B., Samo, K. B. & Ibrahim, M. Z. (2011). Ocean Wave Measurement and Wave Climate Prediction of Peninsular Malaysia. *Journal of Physical Science*, 22(1), 77 – 92.

Nagai, T., Kato, T., Moritani, N., Izumi, H., Terada, Y. & Mitsui, M. (2007). Proposal of Hybrid Tsunami Monitoring Network System Consisted of Offshore Coastal and On-site Wave Sensors. *Coastal Engineering*, 49(1), 213 – 223.

Nagai, T., Kato, T., Moritani, N., Izumi, H., Terada, Y. & Mitsui, M. (2006). Offshore Tsunami Monitoring Network Design Using GPS Buoys and

Coastal On-Site Sensors. *Proceeding of the Coastal Engineering Conference*, 30, 1529 – 1534.

Nagai, T., Ogawa, H., Terada, Y., Kato, T. & Kudaka, M. (2003). Offshore wave, tsunami and tide observation using GPS buoy, *Proceedings of Annual Meeting of Korean Society of Coastal and Ocean Engineers*, Korean Society of Coastal and Ocean Engineers, 14, 137 – 142.

Nagai, T., Satomi, S., Terada, Y., Kato, T., Nukada, K. & Kudaka, M. (2005). GPS buoy and seabed installed wave gauge application to offshore tsunami observation. *Proceedings of the Fifteenth International Offshore and Polar Engineering Conference*, South Korea, 292 – 299.

National Data Buoy Center (NDBC). (2010). Retrieved on January 4, 2014, from http://www.ndbc.noaa.gov/.

National Oceanic and Atmospheric Administration. (2013). Retrieved on March 10, 2014, from http://co-ops.nos.noaa.gov/images/restfig6.gif

O'Reilly, W. C., Herbers, T. H. C., Seymour, R. J. & Guza, R. T. (1996). A Comparison of Directional Buoy and Fixed Platform Measurements of Pacific Swell. *Journal of Atmospheric and Oceanic Technology*, 13(1), 231 – 238.

Oceanor, (2014). Oceanor Seawatch Deep Sea Module. Retrieved on January 18, 2015, from http://www.oceanor.no/seawatch/buoys-and-sensor/Seawatch-deep-sea-module.

Ohta, Y., Meilano, I., Sagiya, T., Kimata, F. & Hirahara, K. (2006). Large surface wave of the 2004 Sumatra-Andaman earthquake captured by the very long baseline kinematic analysis of 1-Hz GPS data. *Earth Planets Space*, 58, 153 – 157.

Parker, B., Milbert, D., Hess, K. & Gill, S. (2003). National VDatum–The implementation of a national vertical datum transformation database. In*Proceeding from the US Hydro'2003 Conference* (pp. 24-27).

Pinardi, N. & Woods, J. (2002). *Ocean Forecasting Conceptual Basis and Applications*. 1st ed. New York, United State America: Springer.

Reeve, D., Chadwick, A. & Fleming, C. (2004). *Coastal engineering: processes, theory and design practice*. Florida, United State America: CRC Press.

Salleh, A. M. & Daud, M. E. (2015). Development of a GPS Buoy for Ocean Surface Monitoring: Initial Results. *World Academy of Science, Engineering and Technology*, 9(6), 1579 – 1582.

Salleh, A. M. & Daud, M. E. (2015a). A Buoy. IP Rights Malaysia. 15-01410-0101.

Salleh, A. M. & Daud, M. E. (2016). An observation technique and GPS buoy processing strategy for ocean surface monitoring. in Dong-Keon Kim, D. K., Jung, J. and Seo, J. (Ed). *Advances in Civil, Architectural, Structural and Constructional Engineering*. London: Taylor & Francis Group. 347 – 350.

Salleh, A. M. & Daud, M. E. (2016a). GPS-Based Ocean Wave Monitoring System for The Strait of Malacca. *Proc. of the 2016 Advanced Research in Engineering and Information Technology International Conference*. Bandung, Indonesia: Maltesas. pp. 68.

Schmidt, W., Woodward, B., Millikan, K., Guza, R., Raubenheimer, B. & Elgar, S. (2003). A GPS-Tracked Surf Zone Drifter. *Journal of Atmospheric and Oceanic Technology*, 20 (7), 1069 – 1075.

Schueler, T., Zimmermann, B., Riedal, B. & Hein, G. W. (2003). Radar altimeter calibration of the Envisat satellite: An autonomous system of high precision for instantaneous sea surface height determination. *Proceeding of the NTM 2003-National Technical Meeting*, Anaheim, California, United State America, 397 – 406.

Schuler, D. L., Lee, J. S., Kasilingam, D. & Pottier, E. (2004). Measurement of ocean surface slopes and wave spectra using polarimetric SAR image data. *Remote Sensing of Environment*, 91(2), 198 – 211.

Schulz-Stellenfleth, J. & Lehner, S. (2004). Measurement of 2-D sea surface elevation fields using complex synthetic aperture radar data. *IEEE Transactions on Geoscience and Remote Sensing*, 42(6), 1149 – 1160.

Segar, D. A. (1998). *Introduction to ocean sciences* (No. 551.46 SEG).

Seidelmann, P. K., Archinal, B. A., A'hearn, M. F., Conrad, A., Consolmagno, G. J., Hestroffer, D. & Stooke, P. (2007). Report of the IAU/IAG Working Group on cartographic coordinates and rotational elements: 2006. *Celestial Mechanics and Dynamical Astronomy*, *98*(3), 155-180.

Shone, T. (2000). GPS Water Level Measurements. Final Report SSG2.194. *Presented at the EGS General Assembly*,Nice, France.

Shum, C., Yi, Y., Cheng, K., Kuo, C., Braun, A., Calmant, S. & Chamber, D. (2003). Calibration of Jason-1 altimeter over Lake Erie. *Marine Geodesy*, 26, 335 – 354.

Snider, F. G. (2016). GPS: Theory, Practice and Applications. Retrieved on February 01, 2016, from http:// www.pdhcenter.com/courses/|116/| 116content.html.

Soares, C. G. & Carvalho, A. N. (2012). Probability distributions of wave heights and periods in combined sea-states measured off the Spanish coast. *Ocean Engineering*, *52*, 13-21.

Sontek, (2015). Retrieved on August 24, 2015, from http://www.sontek.com/productsdetail.phpADP-Acoustic-Doppler-Profiler-4.

Sorensen, R. M. (2006). Basic Coastal Engineering. Chapter 2: Two-Dimensional Wave Equations and Wave Characteristics.

Steele, K. E., Chung-Chu, T. & Wang, D. W. C. (1992). Wave Direction Measurements using Pitch-Roll Buoys. *Ocean Engineering*, 19(4), 349 – 375.

Stokes, G. G. (1880). Theory of Oscillatory Waves. *Mathemathical and Physical Papers*, 1, 313 – 326.

Taira, K., Saadon, M. N., Kitagawa, S. & Yanagi, T. (1996). Observation of temperature and velocity in the coastal water off Kuala Terengganu Malaysia. *Journal of Oceanography*, 52, 251 - 257.

Talley, L. D., Pickard, G. L., Emery, W. J. & Swift, J. H. (2001). Descriptive physical oceanography. San Diego, United State America: Elsevier.

Terada, Y., Kato, T., Itoh, T., Nagata, S., Fujita, T., Abe, T., Miyake, T., Nagai, T., Koshimura, S. & Miyazaki, S., (2003). A new tsunami detection system using RTK-GPS in Ofunato city, *Proceeding of the IUGG* 2003, Northeastern Japan.

Thurman, H. V. & Trujillo, A. P. (2004). *Introductory Oceanograpy*. 10th ed. New Jersey, United State America: Pearson Prentice Hall.

Tolman, H. L. (2008, May). Practical wind wave modeling. In *Proc. CBMS Conf. Water Waves: Theory and Experiment*.

Topper, M. B. R. (2013). Semantics of Spectral Density for Ocean Waves. Institute of Energy Systems Report, The University of Edinburgh, 1b.

Torge, W. (2001). Geodesy. Third completely revised and extended edition.

Triaxys, (2014). Triaxys Directional Wave Buoy. Retreived on November 18, 2014 from http://axystechnologies.com/triaxys-wave-buoy-lp/.

Utusan Malaysia. (2012). Hakisan pantai kian serius. Utusan Melayu (M) Berhad.

Vries, J. J., Waldron, J. and Cunningham, V. (2003). Field tests of the new Datawell DWR-G GPS wave buoy. *Sea Technology*, 44, 50–55.

WAFO, (2000). WAFO - A Matlab Toolbox for Analysis of Random Waves and Loads - A Tutorial. Retreived from http://www.maths.lth.se/matstat/wafo.

Waseda, T., Sinchi, M., Kiyomatsu, K., Nishida, T., Takahashi, S., Asaumi, S., Kawai, Y., Tamura, H. & Miyazawa, Y. (2014). Deep water observations of extreme waves with moored and free GPS buoys. *Ocean Dynamics*, 64, 1269 – 1280.

Watson, C., Coleman, R. & Handsworth, R. (2008). Coastal tide gauge calibration: A case study at Macquarie Island using GPS buoy techniques. Journal of Coastal Research, 24(4), 1071 – 1079.

Watson, C., Coleman, R., White, N., Church, J. & Govind, R. (2003). Absolute calibration of TOPEX/Poseidon and Jason-1 using GPS buoys in Bass Strait, Australia. *Marine Geodesy*, 26, 285 – 304.

Whitney, M. M. & Richard, W.G. (2007). Estimating tidal current amplitudes outside estuaries and characterizing the zone of estuarine tidal influence. *Continental Shelf Research*. 28(3), 380 – 390.

Williams, S. D. P., Bock, Y., Fang, K. P., Jamason, P., Nikolaidis, R. M., Prawirodirdjo, R. M., Miller, M. & Johanson, D. J. (2004). Error analysis of continuous GPS position time series, *Journal of Geophysical Research*, 109(B3).

Wilson, R. M. (2012). Archimedes's principle get updated. PhysicsToday. 65(9), 15.

Wire Mesh Machine. (2014). Hot dipped wire galvanizing line. Retrieved on October 27, 2014 from http://www.china-anbermachine.com/Hot-dipped-wire-galvanizing-line.html.

Witte, T. H. & Wilson, A. M. (2005). Accuracy of WAAS-enabled GPS for the determination of position and speed over ground. *Journal of Biomechanics*, 38(8), 1717 – 1722.

Wu, C., Congwei, H., Zhihua, L., Yongqi, C., Xiaoli, D., Shan, G. & Shengyue, J. (2004). Kinematic GPS Precise Point Positioning for Sea Level Monitoring with GPS Buoy. *Journal of Global Positioning Systems*, 3(2), 302 – 307.

Xu, G. (2003). *GPS : Theory, Algorithms and Applications*. 2nd ed. Berlin, Germany: Springer-Verlag.

Yaakob, O., Zainudin, N. & Shariff, R. , 2004. Developing Malaysian Ocean Wave Database Using Satellite Altimeter. *Proceeding of the Marine Technology Conference (MARTEC 2004)*, Johor, Malaysia.

Yamaguchi, I., Kasai, T., Igawa, H., Harigae, M., Komori, S., Shigenaga, T. & Hosaka, Y. (2005). Ocean wave sensing system using point positioning GPS receiver. *Proceeding in the Space Engineering Conference*, 14, 29 – 34.

Yang, M. & Lo, C. F. (2000). Real-Time Kinematic GPS Positioning for Centimeter Level Ocean Surface Monitoring. *Proceeding of the National Science Councils*, Republic of China, 24(1), 79 – 85.

Yoo, Y., Hou, D., Kouguchi, N., Ishida, H., Shiotani, S. & Fujii, H. (2004). Arrayed GPS-buoys wave observation system. *IEEE Techno Ocean 04*, 3, 1370 – 1375.

Young, L. E., Wu, S. C. & Dixon, T. H. (1986). Decimeter GPS positioning for surface element of sea floor geodesy system. *Proceeding of the International Symposium on Marine Positining*, Reston, Virginia, United State America.

Zappa1, C. J., Banner, M. L., Schultz, Corrada-Emmanuel, H. A., Wolff, L. B. & Yalcin, J. (2008). Retrieval of short ocean wave slope using polarimetric imaging. *Measurement Science and Technology*, 19(5).

Zhang, Z., Law, C. L. & Guanwan, E. (2007). Multipath mitigation technique based on partial autocorrelation function. *Wireless Personal Communication*, 41, 145 – 154.