UNIVERSITI PUTRA MALAYSIA

GENERATION AND EVALUATION OF DIGITAL ELEVATION MODEL DERIVED THROUGH SPACEBORNE SYNTHETIC APERTURE RADAR INTERFEROMETRY

KU MOHD NOH BIN HJ KU RAMLI

GENERATION AND EVALUATION OF DIGITAL ELEVATION MODEL DERIVED THROUGH SPACEBORNE SYNTHETIC APERTURE RADAR INTERFEROMETRY

By

KU MOHD NOH BIN HJ KU RAMLI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

August 2007

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

GENERATION AND EVALUATION OF DIGITAL ELEVATION MODEL DERIVED THROUGH SPACEBORNE SYNTHETIC APERTURE RADAR INTERFEROMETRY

By

KU MOHD NOH BIN HJ KU RAMLI

August 2007

Chairman : Professor Shattri bin Mansor, PhD

Faculty : Engineering

Many success stories of spaceborne InSAR have been reported all over the world in various earth sciences applications. However, only a limited number of articles were reported for applications in tropical regions. Therefore the objectives of this research are: i) To generate DEM from repeat pass spaceborne InSAR by using SAR data from European Earth's Resource Satellite (ERS-1 and ERS-2), Canadian Earth Resource Satellite (Radarsat) which are both in C-band systems and L-band Japanese Earth Resource Satellite (JERS-1) with emphasise on coherence optimisation; ii) To increase the coherence level through slope enhancement technique; and iii) To assess the potential, suitability and limitations of InSAR DEM generated from

the above data and conducting accuracy assessment of the InSAR DEM in Malaysian condition.

Two test sites (Site A-Selangor and Site B-pahang) were selected for their variability in vegetations cover and landforms. Three pairs of ERS tandem data (pair 1, pair 2 and pair 3), one pair of JERS-1 data (pair 5) and one pair of standard mode Radarsat S7 data (pair 7) were acquired for site A-Selangor. On the other hand, one pair ERS tandem data (pair 4) and one pair JERS-1 data (pair 6) were acquired for site B-Pahang. Despite of having many pairs of data, the generation of DEM for site A-Selangor was not very successful. The ERS tandem data has revealed a very low coherence level (< 0.3) for almost all vegetations cover with exception for urban and suburban areas (> 0.5). The clearly visible interferogram pattern could be seen in higher coherence areas. However, the atmospheric artifacts can be observed clearly on the interferogram through 'fuzzy' fringe pattern especially along the coastline. The Radarsat and JERS-1 data have shown a poorer coherence and interferogram quality, eventhough slightly better results for JERS-1 comparatively, presumably due to the long temporal separation of 24 days and 44 days between the two successive data acquisitions. ERS tandem data over site B-Pahang has shown a promising result with 65% of the ERS scene especially in urban and areas with low vegetations was successfully generated. A long dry month and non-windy condition was assumed to be the contributing success factor. The forested areas especially in high relief areas remain ingenerated. The use of Radarsat and JERS-1 data did not improve the DEM generation. The temporal separation between

the data pair was long enough to observe changes within the canopy and hence the data pairs were totally uncorrelated.

DGPS field observations were conducted to improve the accuracy of InSAR derived DEM and for the accuracy assessment. The third order polynomial warping with thirteen GCP (X, Y) and fourteen GCP (Z) were used for the transformation of DEM from relative to absolute height with the RMSE of 2.4 m, 0.52 m and 1.78 m in X, Y and Z respectively. Quantitative accuracy assessments by using RMSE and R^2 regression correlation analysis were performed on the InSAR DEM against DGPS points, spot height check points, contour generated DEM, SRTM Mean Sea level DEM and SRTM WGS84 DEM. A Root Mean Square Error (RMSE) of 12.619, 15.662, 15.421, 15.016 and 15.694 were reported for the analysis accordingly. The corresponding R^2 results of 0.8598, 0.913, 0.914, 0.8948 and 0.8938, obtained from similar evaluation pairs proved they are highly correlated. The results were satisfactory and agreeable to the results from most researches. The qualitative assessment was performed and presented graphically to further emphasis on the quality of the results.

ERS tandem data is capable to provide a medium scale DEM at 1: 100 000 or smaller with accuracy within 20-25 m and contour interval of 40 m. This is absolutely complementing the present techniques of producing DEM especially in areas that is constraint by the persistent cloud cover through out the year. This complementary approach is considered as the best approach to expedite the generation of DEM for the whole country. Spaceborne ERS

tandem data eventhough with one day temporal separation is still insufficient to ensure a highly correlated image pairs for 100% success in generating DEM. The DEM quality will be tremendously improved with single pass InSAR where the data was acquired by the two sensors simultaneously which is currently available only in airborne and shuttle environment. Therefore, single pass data acquisition should ideally be the preference for this part of the world such that have been proven by airborne Airsar Topsar Pacrim I and II missions in 1996 and 2000 and SRTM.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENJANAAN DAN PENGANALISAAN DEM YANG DIHASILKAN MELALUI KAEDAH INTERFEROMETRI *SYNTHETIC APERTURE RADAR* ANGKASA

Oleh

KU MOHD NOH BIN HJ KU RAMLI

Ogos 2007

Pengerusi : Profesor Shattri bin Mansor, PhD

Fakulti : Kejuruteraan

Kejayaan penjanaan DEM daripada teknik interferometri (InSAR) telah banyak dilaporkan dalam pelbagai bidang aplikasi sains bumi di serata dunia. Namun begitu, tidak banyak kajian yang telah dijalankan untuk aplikasi di kawasan tropika yang penuh dengan tumbuhan. Oleh itu, objektif penyelidikan ini ialah untuk: i) Menjana DEM InSAR angkasa dengan menggunakan data dari *European Earth's Resource Satellite* (ERS-1 and ERS-2*), Canadian Earth Resource Satellite* (Radarsat) yang mana kedua-duanya adalah sistem jalur C dan *Japanese Earth Resource Satellite* (JERS-1) yang menggunakan jalur L dengan mengoptimakan *coherence*; ii) Untuk meningkatkan tahap *coherence* dengan menggunakan teknik penonjolan

cerun *(slope enhancement technique);* dan iii) Menilai keupayaan, kesesuaian dan kekurangan DEM InSAR yang dihasilkan dengan menggunakan data yang dihasilkan di atas dan menjalankan penganalisaan ketepatan di persekitaran Malaysia.

Dua kawasan kajian (kawasan A-Selangor dan kawasan B-Pahang) telah dipilih kerana kepelbagaian bentuk dan litupan buminya. Tiga pasang data tandem ERS (pasangan 1, 2 dan 3), sepasang data JERS-1 (pasangan 5) dan sepasang data Radarsat (pair 7) telah diperolehi untuk Tapak A-Selangor. Sementara itu, sepasang data tandem ERS (pasangan 4) dan sepasang data JERS-1 (pasangan 6) telah diperolehi untuk kawasan Tapak B-Pahang. Walaupun kawasan A-Selangor mempunyai banyak pasangan data, penjanaan DEM kawasan ini tidak begitu berjaya. Data tandem ERS telah menunjukkan kadar koheren yang rendah (<0.3) pada semua litupan bumi kecuali bagi kawasan perbandaran dan sub-perbandaran (>0.5). Bentuk interferogram yang jelas telah ditunjukkan pada kawasan yang mempunyai kadar koheren yang tinggi. Walaupun begitu, kesan *atmospheric artifacts* dapat dilihat dengan jelas melalui bentuk interferogram yang tidak jelas terutamanya di sepanjang pantai. Kedua-dua data radarsat dan JERS-1 L band telah menunjukkan kualiti koheren dan interferogram yang rendah, walaupun JERS-1 menghasilkan kualiti data yang sedikit lebih baik berbanding radarsat, berkemungkinan disebabkan kerana jarak masa yang panjang di antara kedua-dua data bagi setiap pasangan iaitu 24 hari dan 44 hari masing-masing. Data tandem ERS kawasan B-Pahang telah menunjukkan hasil yang memberansangkan di mana penjanaan DEM telah

berjaya dilaksanakan bagi 65% daripada kawasan bertindih pasangan data tersebut terutamanya di kawasan perbandaran dan kawasan bertumbuhan rendah. Kemarau yang panjang dan keadaan tiada angin bertiup adalah merupakan di antara faktor utama kejayaan penjanaan DEM di kawasan ini. Penjanaan DEM di kawasan berhutan tebal terutama di tanah tinggi tetap tidak berjaya. Penggunaan data Radarsat dan JERS-1 tidak dapat membantu meningkatkan kualiti penjanaan. Jarak masa di antara kedua-dua data bagi setiap pasangan adalah terlalu panjang sehingga membolehkan pengesanan perubahan pada tumbuhan yang seterusnya mengakibatkan pasangan data tersebut tidak mempunyai kaitan langsung.

Cerapan DGPS di lapangan telah dijalankan bertujuan meningkatkan kualiti DEM InSAR dan juga untuk analisa kejituan. Polinomial darjah ketiga telah digunakan untuk menukar DEM berketinggian relatif kepada DEM berketinggian absolut menggunakan 13 GCP (X,Y) dan 14 GCP (Z) DGPS dengan memperolehi nilai RMSE 2.4 m, 0.52 m, 1.78 m bagi X, Y dan Z masing-masing. Analisa kejituan secara kuantitatif dengan menggunakan RMSE dan korelasi regresi R^2 telah dijalankan pada DEM InSAR berbanding titik cerapan DGPS, spot height check points, DEM daripada kontor, DEM SRTM aras purata laut dan DEM SRTM WGS84. Hasil RMSE 12.619, 15.662, 15.421, 15.016 dan 15.694 telah diperolehi bagi setiap perbandingan mengikut turutan yang telah dijalankan. Nilai R^2 yang diperolehi melalui perbandingan yang serupa telah menghasilkan nilai 0.8598, 0.9130, 0.9140, 0.8948 dan 0.8938 masing-masing dan ini menunjukkan nilai korelasi yang tinggi bagi setiap perbandingan yang

dijalankan. Hasil yang diperolehi adalah memuaskan dan selari dengan hasil yang diperolehi oleh penyelidik yang lain. Analisa kualitatif telah juga dijalankan secara grafik untuk lebih menguatkan lagi kualiti yang dihasilkan.

Data tandem ERS berkemampuan untuk menyediakan DEM skala pertengahan pada 1: 100 000 ataupun lebih kecil dengan kejituan 20-25 m dan sela kontor optima pada 40 m. Ini sudah tentu sekali akan saling melengkapi dengan teknik yang sedia diamalkan sekarang ini terutama sekali di kawasan yang di penuhi awan di sepanjang tahun. Kaedah saling melengkapi ini adalah kaedah yang paling bersesuaian untuk mempercepatkan penjanaan DEM di seluruh negara. Data tandem ERS angkasa, walaupun berselang hanya sehari di antara keduanya masih lagi belum mencukupi untuk menjamin imej berkualiti tinggi yang boleh menjana 100% kawasan tindihan pasangan data tersebut. Kualiti DEM yang dihasilkan akan dapat dipertingkatkan secara mendadak dengan menggunakan *single pass InSAR* di mana cerapan data dilakukan secara serentak dengan menggunakan dua penderia. Teknik ini pada masa ini hanya terdapat pada sistem pesawat dan *shuttle* sahaja. Oleh yang demikian, pengambilan data secara *single pass* adalah yang terbaik untuk menyelesaikan masalah penghasilan DEM di kawasan tropika seperti mana yang telah dibuktikan melalui data SRTM dan misi pengambilan data pesawat Airsar/Topsar Pacrim I dan II NASA pada tahun 1996 dan 2000.

ACKNOWLEDGEMENTS

بِسْمِ اللهِ الرَّحْمٰنِ الرَّحِيمِ

Praise and glory to Allah the Almighty for his blessing which permits me to successfully complete this thesis. I would like to convey my deepest gratitude to my supervisor Professor Dr. Shattri bin Mansor for his precious guidance, encouragement and constructive criticisms throughout this research study. Sincere thanks and appreciation are also extended to other Supervisory Committee Members comprising Associate Professor Dr. Noordin Ahmad and Dr. Muhamad Radzali Mispan for their continuous advices and comments.

My highest appreciations go to Mr. Darus Ahmad, Director of MACRES and Dato' Nik Nasruddin Mahmood, former Director of MACRES for their continuous support and encouragement.

I have no words to express my sincere appreciation to Atlantis Scientific Inc. Ottawa, Canada especially to Dr. Marko Van de Kooij and Dr. Shinya Sato for their experts' guidance and comments in the subject matter and processing of the data using APP and EVInSAR software. I am very much indebted to European Space Agency (ESA), Frascatti, Italy for graciously providing ERS data to materialise this research.

Not to forget, thanks to all staff of UPM who directly and indirectly involve in making this study a success especially the staff of Engineering faculty and Institute of Advanced Technology (ITMA).

Last but not the least, my deepest admiration to my dear wife; Noorma Aziz, daughters; Ku Siti Farhana, Ku Siti Syahidah, Ku Nazurah Husna and Ku Nurul Izzah, and son; Ku Ahmad Lutfi, not only for their patience, kind understanding and supports while preparing the thesis, but also providing courage and inspiration without which this research study would not have been a successful one.

I certify that an Examination Committee has met on 23rd August 2007 to conduct the final examination of Ku Mohd Noh bin Ku Ramli on his Master of Science thesis entitled "Generation and Evaluation of Digital Elevation Model Derived Through Spaceborne Synthetic Aperture Radar Interferometry" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Master of Science.

Members of the Examination Committee were as follows:

Kamaruzaman Jusoff, PhD
Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Ahmad Rodzi Mahmud, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Helmi Zulhaidi Mohd Shafri, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mazlan Hashim, PhD
Professor
Faculty of Engineering and Geoinformation Science
Universiti Teknologi Malaysia
(External Examiner)

HASANAH MOHD. GHAZALI, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 28 April 2008

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Shattri Mansor, PhD
Professor
Engineering Faculty
Universiti Putra Malaysia
(Chairman)

Noordin Ahmad, PhD
Associate Professor
Engineering Faculty
Universiti Putra Malaysia
(Member)

Muhamad Radzali Mispan, PhD
Senior Research Officer
Malaysian Agriculture Research and Development Institute (MARDI)
(Member)

_____
AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 8 May 2008

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any degree at Universiti Putra Malaysia or other institution.

_____

KU MOHD NOH BIN HJ KU RAMLI

Date: 20 March 2008

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	Three Dimensional
AIRSAR	NASA's Airborne Synthetic Aperture Radar
APP	Advanced Precision Processor software
ASEAN	Association of South East Asean Nations
CAMS	Computer Assisted Mapping Systems
CEOS	Committee of Earth Observation System
CEOS PPR	CEOS Platform Position Record
CRISP	Centre for Remote Imaging, Sensing and Processing
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DInSAR	Differential SAR Interferometry
DTM	Digital Terrain Model
DXF	Data Exchange Format
EC	European Community
ECI	Earth Centered Inertial
ECR	Earth Centered Rotation
EDM	Electronic Distance Measurements
EMR	Electromagnetic Radiation
ERS-1	European Earth Resource Satellite-1
ERS-2	European Earth Resource Satellite-2
ESA	European Space Agency
EVInSAR	EarthView SAR Interferometry software
GCP	Ground Control Point
GIS	Geographic Information System

GlobeSAR	Canadian Airborne SAR System
GPS	Global Positioning System
GRS	Ground Reference System
H	Horizontally polarized
HH	Horizontal polarized transmission, horizontal polarized reception
HV	Horizontal polarized transmission, vertical polarized reception
InSAR	SAR Interferometry
IKONOS	IKONOS, launched on September 24, 1999 is the first commercial high-resolution satellite.
IPL	Input Parameter List
LANDSAT ETM	Enhanced Thematic Mapper sensor on board LANDSAT satellite records 7 spectral bands of 30m resolution and one panchromatic band of 12.5m resolution
LIDAR	Light Detection and Ranging
JERS	Japanese Earth Resource Satellite
JPL	Jet Propulsion Laboratory
JUPEM	Jabatan Ukur dan Pemetaan Malaysia
MACRES	Malaysian Centre for Remote Sensing
MSL	Mean Sea Level
MMU	Multi Media University
MOSTI	Ministry of Science, Technology and Innovation
MOU	Memorandum of Understanding
MLD	Multi Look Detected format
NASA	National Aeronautics and Space Agency
NCC	Network Control Centre

PACRIM	Pacific Rim Mission
PSInSAR	Permanent Scatterers InSAR
R&D	Research and Development
RADAR	RAdio Detection And Ranging
RADARSAT	Canadian Earth Resource Satellite
RESTEC	Remote Sensing Technology Center of Japan
RMS	Root Mean Square
RMSE	Root Mean Square Error
RSO	Rectified Skew Orthomorphic Projection System
RSP	Reference System for Planning
S7	The RADARSAT image with standard mode 7
SA	Selective Availability
SAR	Synthetic Aperture Radar
SEASAT	The first earth-orbiting satellite designed for remote sensing of the earth's oceans and had onboard the first spaceborne SAR
SLAR	Side Looking Airborne Radar
SLC	Single Look Complex
SPOT	System Probatoire d'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
TOPSAR	NASA's Topographic SAR system onboard AIRSAR
TP	Tie Point
UN	United Nations
V	Vertically polarized
VIR	Visible and Infra Red
VH	Vertical polarized transmission, horizontal polarized reception