Jurnal
Teknologi

Full Paper

COMPARATIVE ANALYSIS OF ASTER DEM, ASTER GDEM, AND SRTM DEM BASED ON GROUND-TRUTH GPS DATA

Article history
Received
18 January 2015
Received in revised form
18 March 2015
Accepted
1 August 2015

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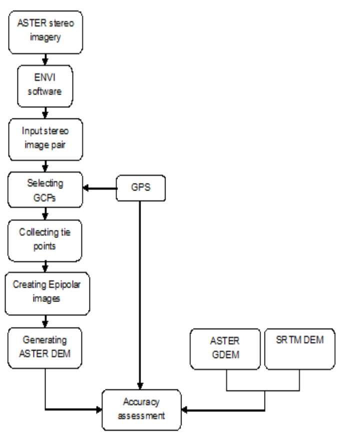
Graphical abstract



Abstract

This study aims to compare the accuracies of ASTER DEM, ASTER GDEM, and SRTM DEM for the area of Universiti Teknologi Malaysia (UTM) and surrounding. In doing so, a number of Ground Control Points (GCPs) were collected using GPS technology and used to generate an absolute DEM using the ASTER stereo imagery. Moreover, two well-known DEMs including ASTER GDEM and SRTM DEM were obtained for the same area with ASTER image. Subsequently, several high accuracy ground-truth points were established around UTM using dual frequency GPS and used to assess the accuracies of the obtained DEMs. The results indicate that an elevation Root Mean Square Error (RMSE) of ±14.86m is achieved for the generated ASTER DEM, which is less than the 15m pixel size of ASTER image. The results further show that the elevation RMSEs of the ASTER GDEM and SRTM DEM are respectively ±4.52m and ±4.14m for the study area. The results illustrate although the resolution of SRTM DEM is much lower than ASTER GDEM, it could provide higher elevation accuracy. Finally, although the accuracy of the ASTER DEM in this study is not high in comparison with the accuracies of ASTER GDEM and SRTM DEM, based on the selected number of check points and resolution of ASTER image, it could be useful for various geoinformation applications.

Keywords: ASTER, SRTM, DEM, GPS, accuracy assessment

Abstrak

Kajian ini bertujuan untuk membandingkan ketepatan daripada DEM ASTER, GDEM ASTER dan DEM SRTM bagi kawasan Universiti Teknologi Malaysia (UTM) dan sekitarnya. Dalam kajian ini, beberapa titik kawalan bumi (GCP) telah dikumpulkan dengan menggunakan teknologi GPS dan digunakan untuk menjana DEM mutlak menggunakan imej stereo ASTER. Tambahan pula, dua DEM terkenal termasuk ASTER GDEM dan SRTM DEM telah diperolehi bagi kawasan yang sama dengan imej ASTER. Seterusnya, beberapa titik-titik pengesahan lapangan ketepatan tinggi ditubuhkan di sekitar UTM dengan menggunakan frekuensi dual GPS dan digunakan untuk menilai ketepatan DEM. Keputusan menunjukkan bahawa punca kuasa dua seliseh (RMSE) ±14.86m dicapai untuk DEM ASTER yang dihasilkan yang kurang daripada saiz 15m piksel imej ASTER. Keputusan lanjut menunjukkan bahawa ketinggian RMSE GDEM ASTER dan SRTM DEM masing-masing adalah ±4.52m dan ±4.14m bagi kawasan kajian. Keputusan menunjukkan walaupun resolusi SRTM DEM adalah jauh lebih rendah daripada GDEM ASTER, ia boleh memberikan ketepatan ketinggian yang lebih tinggi. Akhir sekali, walaupun ketepatan DEM ASTER yang dihasilkan dalam kajian ini tidak tinggi berbanding dengan ketepatan daripada GDEM ASTER dan DEM SRTM berdasarkan bilangan titik semakan dan resolusi imej ASTER, ia boleh menjadi berguna untuk pelbagai aplikasi geoinformasi.

Kata kunci: ASTER, SRTM, DEM, GPS, penilaian ketepatan

1.0 INTRODUCTION

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument which is flying on Terra, a satellite launched in December, 1999 as part of National Aeronautics and Space Administration's (NASA) Earth Observing System (EOS) [1]. The ASTER consists of three separate subsystems for the visible near infrared (VNIR), shortwave infrared (SWIR) and thermal infrared (TIR) spectral regions with the spatial resolutions of 15m, 30m and 90m, respectively [2-3]. The ASTER image dataset was processed by the Japanese Ground Data System (GDS), and archived by the Land Processes Distributed Active Archive Center (LPDAAS) at the United State Geological Survey (USGS) data center. It is onboard the NASA's Terra spacecraft that provides along-track digital stereo image data at 15m resolution. The main advantage of the along-track mode of data acquisition (as compared to the cross-track) is that the images forming the stereo pairs are acquired a few seconds (rather than days) apart under uniform environmental and lighting conditions. So, it results in stereo pairs of consistent quality which are well suited for the generation of Digital Elevation Model (DEM) by automated stereo correlation techniques [4-5].

A digital elevation model is a regularly spaced raster grid of elevation values of a surface terrain. DEMs are useful in generating various maps such as contour, orthophoto and perspective maps. In remote sensing, DEMs are useful in mapping, orthorectification and land classification. The accuracy of a DEM is estimated by comparison of Z values and by contrasting a number of check points with true elevations measured by high precision methods. The pair wise comparisons allow the calculation of Mean Error (ME), Standard Deviation (SD), Root Mean Square Error (RMSE) or similar statistics. It is obvious that although reliability in the accuracy assessment processes is not constant, it can be maintained depending on several factors. The number of check points is one of important factors in the reliability because it conditions the range of stochastic variations on the standard deviation values. The accuracy of generated DEMs based on space images is mainly depending upon the image resolution, the height-to-base-relation and the image contrast [6-7].

The DEM extraction process requires a stereo pair of images containing Rational Polynomial Coefficients (RPC) positioning from aerial photography or pushbroom sensors. RPCs are used in generating the tie points and calculating the stereo image pair relationship. Digital elevation models can be created by stereoscopy, photoclinometry, synthetic aperture radar (SAR) or laser and radar altimetry methods. Stereoscopy requires two images of the same area that are slightly different in viewing angle. The binocular disparity or parallax is the difference between these two images and the convergence angle between the two images determines the degree of disparity. Clinometry method uses shadows to derive elevation for specific objects, such as mountain peaks. This method has been applied to aerial photos and visible infra-red (VIR) satellite images. DEMs can also be generated using traditional photogrammetry based on aerial photos and very often more economic by means of space images. Another possibility is using airborne laser scanning to generate DEMs. Although it is very expensive, it will lead to very detailed and accurate information [8-9].

There are some well-known and available DEMs including SRTM DEM and ASTER GDEM. The SRTM (Shuttle Radar Topography Mission) DEM is a unique product which was produced by NASA (National Aeronautics and Space Administration) and NGA (National Geospatial-Intelligence Agency) in cooperation with German and Italian space agency. NASA has released SRTM DEM at 90 meter resolution covering 80% of the Earth's land surface. This distribution is a giant step leap forward in spatial resolution for digital elevation models with global coverage, and has a positive, significant effect on related researches. The vertical accuracy in the dataset is stated as ±16m at the 90% confidence level. SRTM DEM is distributed in the form of squares of size 1 degree latitude x 1 degree longitude (it represents the area of approximately 111 km x 111 km on equator) [10].

The ASTER Global DEM (GDEM) was developed jointly by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). The methodology used to produce the ASTER GDEM incorporated an automated processing of the entire 1.5 million scene ASTER archive including stereo correlation to produce 1,264,118 individual scene-based ASTER DEMs, cloud masking to remove cloudy pixels, stacking all cloud screened DEMs, removing residual bad values and outliers, averaging selected data to create final pixel values, and then correcting residual anomalies before partitioning the data into 1°-by-1° tiles. Estimated accuracies of ASTER GDEM are 20m at 95% confidence for vertical data and 30m at 95% confidence for horizontal data [11-13].

This study aims at investigating the accuracies of various digital elevation models including the ASTER generated DEM, ASTER GDEM and SRTM DEM for the area of Universiti Teknologi Malaysia and surrounding. In doing so, first a digital elevation model is generated from ASTER stereo imagery for the study area using the ENVI software and manual GCPs selection, where the selected GCPs were collected using GPS technology. The accuracy of the generated DEM is then evaluated and compared with the accuracies of two well-known DEMs including ASTER GDEM and SRTM DEM for the area of Universiti Teknologi Malaysia and surrounding. In this respect, a number of ground-truth points collected using dual frequency GPS, were used as the reference.

2.0 STUDY AREA AND DATASETS

Universiti Teknologi Malaysia is located in the Johor state in southern peninsular Malaysia. It is about 25 km far from Johor Bahru (the capital city of Johor). The study area is bounded by 103˚ 37' 01''E to 103˚ 39' 05''E and 1˚ 34' 35''N to 1˚ 32' 06''N. To reach the aim of this research, a scene of ASTER Level 1A image (bands 3N and 3B), a scene of ASTER GDEM, a scene of SRTM DEM, and a number of ground control points were used as datasets in the study.

3.0 METHODOLOGY

In order to achieve the aim of the study, the following tasks were performed: study area definition, data collection, image processing, and quantitative analysis of the results. Figure 1 show the overall method adopted in this study.

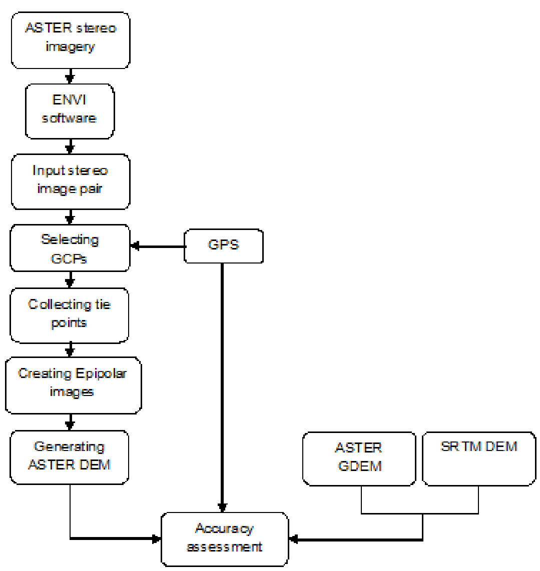


Figure 1 Flowchart of research methodology

The Visible and Near Infra-Red (VNIR) portion of the ASTER sensor includes two independent telescopes, a nadir looking one and a backward looking one to help minimize image distortion during data capture. This simultaneous data capture provides true stereo coverage from which a digital elevation model can be automatically extracted. The VNIR 3N and 3B bands of ASTER imagery used in this study are displayed in Figure 2.

Several ground control points collected using GPS technology, were selected manually in the stereo pair images. Figure 3 shows distribution of the selected GCPs in whole ASTER image and in study area (Universiti Teknologi Malaysia and surrounding).

The processing procedures including: inputting stereo image pair, defining GCPs, defining Tie Points, calculating Epipolar geometry and images, specifying DEM output projection parameters, specifying DEM extraction parameters, creating DEM, and examining the result were carried out using ENVI 4.8 software. The vertical accuracy of the generated DEM was compared with the vertical accuracies of ASTER GDEM and SRTM DEM for the area of Universiti Teknologi Malaysia and surrounding. For this purpose, by using dual frequency GPS, 20 high accuracy (cm level) ground-truth points were collected in the study area and used as the reference to assess accuracy of the DEMs. Distribution of these points is shown in Figure 4.

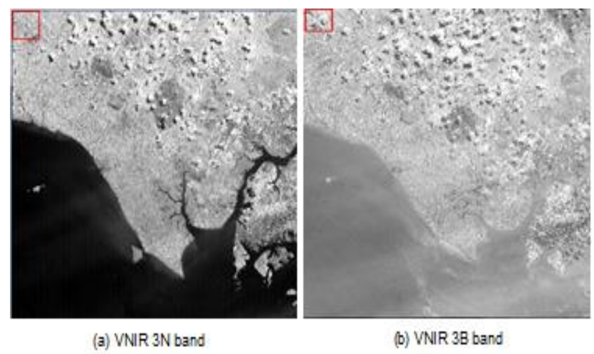


Figure 2 ASTER stereo pair images

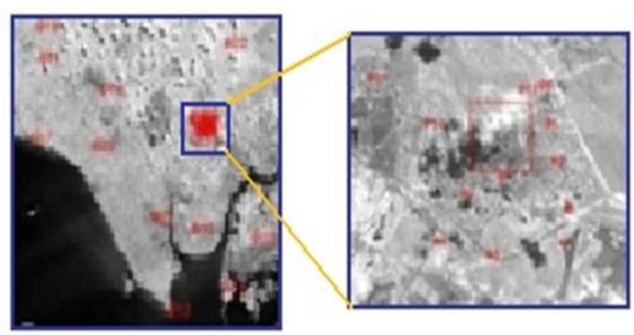


Figure 3 Distribution of GCPs

Figure 4 Distribution of ground-truth points

4.0 RESULTS AND DISCUSSION

Figure 5 shows the resulting ASTER DEM. The original ASTER DEM and the resized DEM to the size of study area are shown in Figures 5a and 5b. The obtained ASTER GDEM and SRTM DEM are shown in Figures 6 and 7, respectively.

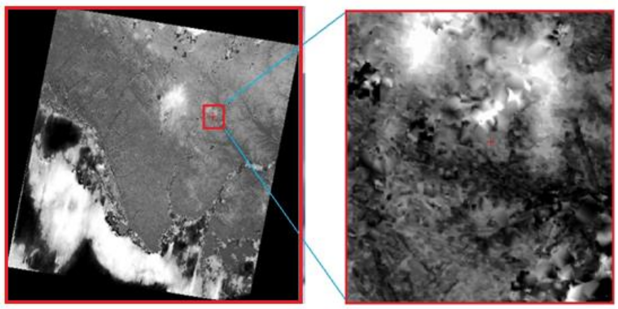


Figure 5 ASTER DEM

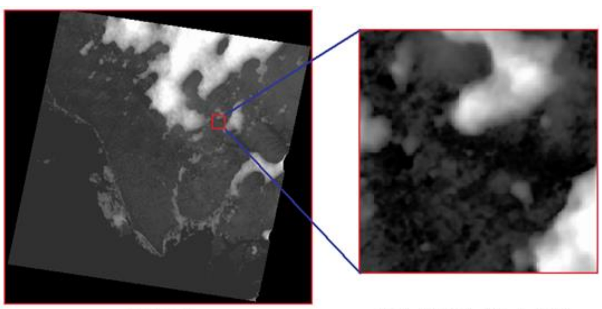


Figure 6 ASTER GDEM

Accuracy of the DEMs is determined by comparing the height of some points in the DEMs with true height of these points. For this purpose, 20 ground-truth points were collected using dual frequency GPS around the study site and were used as the reference for accuracy assessment. In order to assess the accuracies of the DEMs, Mean and Root Mean Square Error (RMSE) values were calculated based on the elevation differences between the DEMs and ground-truth points. The results are summarized in Table 1.

The results show that a Mean and RMSE values of ±12.60m and ±14.86m are achieved for the generated ASTER DEM, which are less than the 15m pixel size of ASTER image. The results further indicate that the Mean values of ASTER GDEM and SRTM DEM are equal to ±3.71m and ±3.85m, while their RMSE values are equal to ±4.52m and ±4.14m, respectively. The results illustrate although the resolution of SRTM DEM is much lower than ASTER GDEM, it could provide higher elevation accuracy. In addition, although the accuracy of the ASTER DEM generated in this study is not high in comparison with the accuracies of ASTER GDEM and SRTM DEM, based on the selected number of check points and the resolution of ASTER imagery, it could be useful for various geoinformation applications.

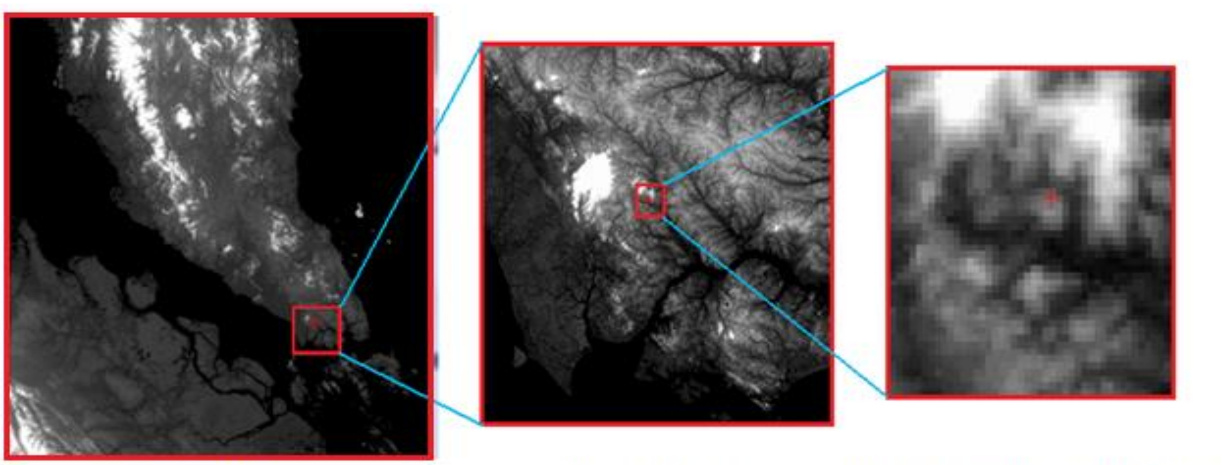


Figure 7 SRTM DEM

Table 1 Accuracy assessment analysis

Ground-truth Point	Easting (m)	Northing (m)	Height of Ground-truth Point (m)	Height in ASTER DEM (m)	Height in ASTER GDEM (m)	Height in SRTM DEM (m)
1	348363	172283	34.5	31	34	33
2	347853	172405	26.0	46	245	29
3	347438	172159	17.0	16	19	22
4	347400	173046	31.5	35	30	36
5	348034	173039	40.0	70	647	44
6	349262	172828	77.0	64	82	82
7	348828	172260	16.0	22	18	22
8	349824	171906	15.0	18	8	17
9	349761	171215	16.0	21	628	19
10	349004	171711	10.0	18	15	16
11	348464	171844	11.5	27	15	18
12	347687	171340	23.5	44	22	29
13	346671	171162	32.0	39	27	35
14	347044	171796	38.0	56	34	39
15	349550	170079	25.5	49	1026	28
16	348944	170510	31.5	40	30	35
17	348345	169893	25.5	47	34	29
18	347603	170025	33.0	50	24	36
19	347524	170694	34.5	47	37	40
20	346879	169812	19.0	34	18	22
		Mean		±12.60	±3.71	±3.85
		RMSE		±14.86	±4.52	±4.14

5.0 CONCLUSION

In this study, a DEM was generated from ASTER stereo imagery for the area of Universiti Teknologi Malaysia (UTM) and surrounding. The DEM was extracted using ENVI software and by selecting 25 ground control points collected using GPS instrument. In addition, two well-known DEM including ASTER GDEM and SRTM DEM were obtained for the same area with ASTER image. The accuracies of the DEMs was assessed through calculation of the Mean and Root Mean Square Error (RMSE) values based on several ground-truth points collected using dual frequency GPS. The results showed that a DEM with a height RMSE of ±14.86m can be achieved using ASTER stereo imagery with a sufficient number of GCPs. The results illustrated higher accuracy of SRTM DEM in comparison with ASTER GDEM for the study area. However, the resolution of ASTER GDEM is much higher than the resolution of SRTM DEM. In conclusion, although the accuracy of the ASTER DEM generated in this study is not high in comparison with the accuracies of ASTER GDEM and SRTM DEM, based on the selected number of check points and the resolution of ASTER image, it could be useful for various geoinformation applications. Moreover, increasing the number of GCPs may improve the accuracy of final output.

Acknowledgement

The authors would like to thank Universiti Teknologi Malaysia (UTM) for providing the facilities for this investigation. We are also grateful to U.S. Geological Survey (USGS) for providing the ASTER image and ASTER GDEM, and the CGIAR Consortium for Spatial Information (CGIAR-CSI) for providing the SRTM DEM.

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