Accuracy Assessment of Digital Elevation Model (DEM) Data Obtained from ASTER Satellite in Flat Land

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Abstract. It is important to investigate the accuracy of Digital Elevation Models (DEMs) because of their crucial impact on all engineering and scientific disciplines. Photogrammetry, traditional surveying, remote sensing systems and satellite whole DEMs output methods. In this paper include the DEM data produced by the ASTER satellite (Band near-infrared wavelength region from 0.78 to 0.86 μm), where tested and evaluation DEM data for an area of 100 square kilometers in Al-Shtra city. The technique used to evaluate was twofold: first method was to use statistical methods; second method is to take advantage of applied linear transformation equation to detect the gap between Z-DEM and Z-Global Navigation Satellite System (GNSS) (which represents reality . The result of a root means square error (RMSE) is 5.087m, where it was calculated based on the observed data in the field using GNSS. And standard deviation error (SDT err) was 5.088 m, while after applied linear transformation equation the RMSE reduction to about 80%, which indicates a large bias between the Z-DEM and Z-GPS.

1. Introduction

Substantial development of science in the remote sensing allowed massive data in a variety of engineering and scientific applications. Perhaps Digital Elevation Models (DEMs) production of important applications in geomatics Engineering based on the principles of remote sensing science. DEMs is an important factor in the creation of an idea about the form of the earth's surface, the integration of advanced computer technologies with engineering or applied science, DEMs is the product of the merger Sciences. Where DEMs applications in geography science, civil engineering, science study climate and environmental engineering, and undoubtedly, the DEMs is an important factor in the survey engineering applications.

A joint project between the U.S. National Aeronautics and Space Administration and Japan’s Ministry of Economy, Trade, and Industry, ASTER has been acquiring data for 15 years, since March 2000. The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) is a 15-channel imaging instrument operating on NASA’s Terra satellite [7]. The ASTER sensor is designed to provide image data in 14 visible, near-infrared, short wavelength infrared and thermal infrared spectral bands.

2. The Study Area

The area of study is located in the south of Iraq with flat terrain topography (Figure 1), Thi-Qar Governorate /AL-Shtra city (31°24'30.17" N, 46°10'32.45" E) which is located from the Baghdad city [Capital of Iraq] about 360 kilometers, the average of the elevation is about 10 meter from the mean sea level.
3. Methodology

To evaluate the ASTER DEM data accuracy in this paper will be according to the following chart (Figure 2), which includes three basics: collection of DEMs data, ground data collection and assessments accuracy.

Figure 1. The study site Thiqar Governorate / AL-Shtra city.

Figure 2. The methodology work
3.1 Data Collection and Fields Works

Digital Elevation Model (DEM) Produce from stereo ASTER stellate image are recorded only in Band 3, which is the near-infrared wavelength region from 0.78 to 0.86 \( \mu m \), using both nadir and aft-looking telescopes (Figure 3). From the nominal Terra altitude of 705 km, the “push broom” linear array sensor covers a 60-km-wide ground track at a 15-m spatial resolution. There is an approximately 60-s interval between the time the nadir telescope passes over a ground location and the aft telescope records the same location on the ground track of the satellite. Images generated from the nadir and aft telescopes yield a B/H ratio of 0.6, which is close to ideal for generating DEMs by automated techniques for a variety of terrain conditions [10] [6].ASTER DEM (version 2) was Available free, the ASTER DEM(V2) was produced as Geotiff format and referenced to the WGS84/EGM96 geoid. ASTER DEM(V2) are available for the user accurately spatial resolution of 30 m.

![Figure 3. Simplified diagram of the imaging geometry for ASTER along-track stereo [6].](image)

To achieve the 95 percent confidence level; there are require to collect thirty Control Point (30 CPs) for study areas. According to Standards American Society for Photogrammetry and Remote Sensing (ASPRS), National Map Accuracy Standards (NMAS) and National Standard for Spatial Data Accuracy (NSSDA) requirements, choose those points in open areas-free residential buildings in low-gradient land, in addition to its proximity to the facilities of an important nature, Intersections on roads and major transportation. The distributions of points in the study area follow the equation (1), to achieve the distance between the points:

\[
\text{Distance between the points}=\frac{d}{10}
\]  

(1)

ASPRS-suggested (1989) systematic sampling method, which ensures that the sample points are well distributed throughout the image being assessed. To implement the ASPRS sample distribution, first, the image is divided into quadrants. Next, a minimum of 20% of the sample points are allocated to each quadrant. To ensure adequate spacing between the sample points, no two points should be closer than \( \frac{d}{10} \) distance from each other, where \( d \) is the diagonal dimension of the map or image. This spacing will minimize spatial autocorrelation. In addition, using the ASPRS systematic sample distribution requires assuming that the sample distribution is not correlated with map or image error. This is a reasonable assumption because the most positional error is correlated with topography, and topography is rarely distributed in a grid pattern [8]. On this basis, in the study area Thi-Qar Governorate /AL-Shtara city It will be the distribution of ground control points (GCPs) as shown in Figure 4. Where the image of study area which covers about 100 km\(^2\) was divided into four quarters, each segment includes the equivalent of 20% of the total number of points, in other words 6points at least in every part. The diagonal distance
of the study area in the 14,000 meters, so it will be the distance between the points is (1400/10=1400 m).

Thirty data Ground Control Points (GCPs) to collect use the device type Topcon device model GR3 Dual-frequency. The static mode was used to observed Basis point (Network approach), with time observation about 10 hours in coincided with the observation CORS(continuously operating reference stations) Stations in Najaf, Kut and Baghdad.

After the completion of the observation process, download the raw data observed from the device to a computer to complete the correction and processing, to be processed and sent to the Online Positioning User Service (OPUS) to complete the correction and processing (Table 1).

Figure 4. Distribution of Ground Control Points (GCPs)
Table 1. Information on Base Point in AL-Shtra city

| Name Point | Coordinates (the unit of measurement meter) |
|------------|---------------------------------------------|
|            | X                       | Y                       | Z           |
| Base Point | 611201.518               | 3474771.039             | 13.035      |
| Base Point A | 609282.410             | 3481101.261             | 8.720       |

After monitoring Base Point process, Ground Control Point three-dimensional (X Y Z) became available; the next step is to observation of thirty control points (30 C.P. 10 kilometer average distance between the Base point and Thirty-control points distributed throughout the Al-Shtra city. Rapid static observation is suitable in terms of accuracy and time [2]. About 30 minutes to monitor fast static (use a radial baseline technique) for each point (Figure 5); the observation was divided into groups. The last group of Control Points (C.P) Which is (C.P27 to C.P30), adopted from Basis Points A .C.P26 is a Basis Point A, they become due to the conditions. So it is useful to use as a Control Point (C.P) in accuracy assessment (Table 2).

Figure 5. A map showing the distribution of control points in Al-Shtra city.
Table 2. Information on Ground Control Points and Z ASTER in AL-Shtra city.

| NAME POINT | Coordinates (the unit of measurement meter) | Y        | X        | Z actual | Z ASTER (V2) |
|------------|--------------------------------------------|----------|----------|----------|--------------|
| C.P1       |                                            | 3471046.9| 611424.34| 7.784    | 15           |
| C.P2       |                                            | 3473222.3| 613004.9 | 7.901    | 7            |
| C.P3       |                                            | 3474137.6| 613794.32| 8.005    | 7            |
| C.P4       |                                            | 3475381.2| 614384.61| 8.503    | 7            |
| C.P5       |                                            | 3475054.7| 615678.55| 8.9      | 14           |
| C.P6       |                                            | 3477538.3| 613275.59| 8.916    | 6            |
| C.P7       |                                            | 3478506.5| 614605.11| 8.625    | 17           |
| C.P8       |                                            | 3481274.1| 613203.2 | 8.598    | 9            |
| C.P9       |                                            | 3481689.5| 615535.29| 10.379   | 5            |
| C.P10      |                                            | 3480929.5| 611764.11| 8.489    | 1            |
| C.P11      |                                            | 3482514.8| 613968.04| 8.113    | 0            |
| C.P12      |                                            | 3480720.2| 610183.85| 11.103   | 8            |
| C.P13      |                                            | 3474766.7| 610404.94| 9.954    | 12           |
| C.P14      |                                            | 3476823.9| 610015.93| 8.678    | 9            |
| C.P15      |                                            | 3481840.0| 608738.87| 8.755    | 13           |
| C.P16      |                                            | 3480207.1| 608709.93| 7.558    | 13           |
| C.P17      |                                            | 3478154.9| 609488.62| 9.478    | 21           |
| C.P18      |                                            | 3478394.1| 608034.13| 6.389    | 10           |
| C.P19      |                                            | 3475842.1| 607123.54| 7.892    | 7            |
| C.P20      |                                            | 3474398.8| 607658.71| 8.404    | 5            |
| C.P21      |                                            | 3471868.8| 612669.6 | 8.384    | 9            |
| C.P22      |                                            | 3476949.6| 614794.09| 7.589    | 12           |
| C.P23      |                                            | 3471135.9| 609282.9 | 7.028    | 5            |
| C.P24      |                                            | 3479220.0| 610509.9 | 8.062    | 10           |
| C.P25      |                                            | 3479975.8| 614248.77| 11.608   | 24           |
| C.P26      |                                            | 3481101.3| 609282.41| 8.72     | 9            |
| C.P27      |                                            | 3477048.7| 608500.83| 7.39     | 8            |
| C.P28      |                                            | 3475713.3| 608892.65| 8.045    | 8            |
| C.P29      |                                            | 3473807.8| 609010.58| 7.95     | 0            |
| C.P30      |                                            | 3472334.0| 610561.26| 8.17     | 12           |

3.2 Z-extract value from the ASTER (V2) DEM layer

The stage extraction value of Z, articulated an important stage to assess the accuracy of the various layers of DEMs. Four basic steps to extract the value of Z: (1) Data entry, (2) data management, (3) analysis and (4) output data, for that, the GIS environment are ideal to complete the task[9]. Enter the ASTER (V2) DEM layer of the DEMs simultaneously with the creation of shapfile(shp*) that contains thirty Ground controller points information (Enter and data management stage). matching layers(DEM layers and feature point layer), use Spatial Analyst Tools to extract the Z value(Table 2)It is the stage of analysis and data output.

3.3 Methods of Assessing Accuracy

3.3.1 Linear Transformation Algorithm

The Computer Assisted and use applications and software to solve the difficult equations became possible and smooth. The linear transformation function (2 and 3) used to achieve a close fit between the Z-GPS and Z-ASTER DEM [6]. In other words, the greater the DEM affected by the linear transformation function given indicates that the large bias between Z-DEM and Z-GPS.

\[
Z = (u,v,w) \\
Z = a.u + b.v + c.w + Z_0
\]
Where:
Z is observation data
w is estimation data
u,v are coordinate of estimation
A linear transformation function will be used to derive bias corrected of the DEMs elevation as follows:
Apply the equation 3 on the first point until n Points

\[ Z_1 = a \cdot u_1 + b \cdot v_1 + c \cdot w_1 + Z_0 \]  
(3a)

\[ Z_2 = a \cdot u_2 + b \cdot v_2 + c \cdot w_2 + Z_0 \]  
(3b)

\[ Z_3 = a \cdot u_3 + b \cdot v_3 + c \cdot w_3 + Z_0 \]  
(3c)

\[ Z_{n-1} = a \cdot u_{n-1} + b \cdot v_{n-1} + c \cdot w_{n-1} + Z_0 \]  
(3d)

\[ Z_n = a \cdot u_n + b \cdot v_n + c \cdot w_n + Z_0 \]  
(3e)

Summarize equation from the equation (3a) to (3e) as follows:

\[ \sum_{i=1}^{n} Z_i = \sum_{i=1}^{n} (a \cdot u_n + b \cdot v_n + c \cdot w_n + Z_0) \]  
(4)

The sum of the squares of deviation is given by:

\[ S(a, b, c, Z_0) = \sum (e_i)^2 = \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i)^2 \]  
(5)

The function \( S(a, b, c, Z_0) \) is a minimum when

\[ \frac{\partial S}{\partial a} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) * (u_i) = 0 \]  
(6a)

\[ \frac{\partial S}{\partial b} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) * (v_i) = 0 \]  
(6b)

\[ \frac{\partial S}{\partial c} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) * (w_i) = 0 \]  
(6c)

\[ \frac{\partial S}{\partial Z_0} = 2 \sum (a \cdot u_i + b \cdot v_i + c \cdot w_i + Z_0 - Z_i) * (1) = 0 \]  
(6d)

Dividing equation 6 by 2 and rearranging yields the normal equations:

\[ a \sum u_i \cdot u_i + b \sum v_i \cdot u_i + c \sum w_i \cdot u_i + Z_0 \sum u_i = \sum Z_i \cdot u_i \]  
(7a)

\[ a \sum u_i \cdot v_i + b \sum v_i \cdot v_i + c \sum w_i \cdot v_i + Z_0 \sum v_i = \sum Z_i \cdot v_i \]  
(7b)

\[ a \sum u_i \cdot w_i + b \sum v_i \cdot w_i + c \sum w_i \cdot w_i + Z_0 \sum w_i = \sum Z_i \cdot w_i \]  
(7c)

\[ a \sum u_i + b \sum v_i + c \sum w_i + Z_0 N = \sum Z_i \]  
(7d)

To represent in a matrix form are shown in equation 8:

\[ AX = B \]  
(8)

Where:

\[ A = \begin{bmatrix}
\sum_{i=1}^{n} u_i \cdot u_i & \sum_{i=1}^{n} v_i \cdot u_i & \sum_{i=1}^{n} w_i \cdot u_i \\
\sum_{i=1}^{n} u_i \cdot v_i & \sum_{i=1}^{n} v_i \cdot v_i & \sum_{i=1}^{n} v_i \cdot w_i \\
\sum_{i=1}^{n} u_i \cdot w_i & \sum_{i=1}^{n} v_i \cdot w_i & \sum_{i=1}^{n} w_i \cdot w_i
\end{bmatrix} \]  
(8a)

\[ X = \begin{bmatrix}
a \\
b \\
c \\
Z_0
\end{bmatrix} \]  
(8b)

\[ B = \begin{bmatrix}
\sum_{i=1}^{n} Z_i \cdot u_i \\
\sum_{i=1}^{n} Z_i \cdot v_i \\
\sum_{i=1}^{n} Z_i \cdot w_i \\
\sum_{i=1}^{n} Z_i
\end{bmatrix} \]  
(8c)

Solving an equation 7 with help MATLAB software required should first organize the elements of the matrix A using Excel software. Extract the values of the parameters (a,b,c and Z0) of the equation 3 and re-applied(Table 3), and obtaining new values Z.
Table 3. Information parameters for ASTER (v2) DEM

| DEMs source | a(m)          | b(m)          | c(m)          | Z0(m)         |
|-------------|---------------|---------------|---------------|---------------|
| ASTER       | 0.0000989319749 | 0.0000887012162 | 0.07227998091312 | -361.0274548083 |

3.3.2 Statistically operations

The definition of the concept of bias: It is the extent of gap and variation data from each other, if bias meter close to zero can say that this kind of data is homogeneous [3] Measures of bias:

\[ \text{Range } z = \text{MAX} _{Z} - \text{MIN} _{Z} \] (9)

Equation 9 Depends on maximum and minimal value only and this may cause problems when abnormal values [5] wherefore use the Mean error, Standard deviation error, and Root means square error formula:

\[ ME = \frac{\sum_{i=1}^{n} Z_{diff(i)}}{n} \] (10)

\[ STD_{err} = \sqrt{\frac{\sum_{i=1}^{n} (Z_{diff(i)} - ME)^2}{n-1}} \] (11)

\[ RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Z_{diff(i)})^2}{n-1}} \] (12)

Where:

\[ Z_{diff} = Z_{DEM} - Z_{GCP} \] (13)

n=The number of samples (points).

4. Results

The maximum value of the error (or difference) recorded ASTER (V2) DEM is 12.392 m and the minimum value was -8.113 m. The RMSE is 5.087 and standard deviation error (SDT err) was 5.088 (Figure.6). The maximum value of the error results after applying correcting Bias is 1.998 m and the minimum value was -2.441 m. The RMSE and SDT error less to 0.992 m, 0.968 m respectively.

After applying the correction equation (linear transformation function) the RMSE dropped to about 80%, which indicates a large bias between the Z-DEM and Z-GPS (Figure.7).

![Figure 6. Statistical operations (RMSE, Mean Error, Max Error, Min Error, SDT Error).](image_url)
5. Conclusion
The digital elevation models (DEM) derived from the near-infrared wavelength which is the region from 0.78 to 0.86 μm of ASTER satellite, achieved accuracy is very low, in the open land with low terrain. This DEM cannot be adopting in civil engineering works definitely.

List of symbols and terminology

- ASPRS: American Society of Photogrammetry and Remote Sensing
- ASTER: Advanced Space borne Thermal Emission and Reflection Radiometer
- DEM: Digital Elevation Models
- DGPS: Global Positioning System differential
- EGM: Earth Gravitational Model
- GCP: ground control point
- GIS: Geographic Information Systems
- NIMA: National Map Accuracy Standard
- NSSDA: National Standard for Spatial Data Accuracy
- OPUS: Online Positioning User Service
- RMSE: Root mean square error
- SDT: Standard deviation error
- SRTM: shuttle radar topography mission
- WGS: World Geodetic System

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