OPTIMIZATION OF DEM INTERPOLATION

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ABSTRACT
Digital Elevation Models (DEMs) are simply regular grids of elevation measurements over the land surface. DEMs are mainly extracted by applying the technique of stereo measurements on images available from photogrammetry and remote sensing. DEMs play a vital role in many scientific, environmental, engineering as well as military applications which need accurate and dense DEMs. However, generating a dense and accurate DEM comes with the price of spending both time and money on the field measurements. Fortunately, advanced space technology has provided much single (if not stereo) high resolution satellite imageries almost worldwide with the available global or local DEMs. This study included evaluating both DEM produced from topographic map and raster DEM after resolution enhancement by using single satellite image. According to the results of these experiments, a strategy was proposed for using the reflectance data to enhance the accuracy of DEM interpolation. The proposed the reflectance data models were implemented in a software package and successfully tested.

[Keywords: Densification of DEM, Spatial Enhancement of DEM, Shape from Shading, Optimization Algorithms]

الخلاصة

نماذج ألارتفاع الرقمية (DEMs) هي ببساطة شبكات منتظمة من ألارتفاعات مقاسة على سطح ألارض. نماذج ألارتفاعات الرقمية (DEMs) تستنبط بشكل رئيسي بتطبيق النماذج المجسمة (زوج من الصور) المتوفرة من المسح التصويري وبيانات التحسس النائي. على أية حال, هنالك الكثير من التطبيقات الهندسية والتطبيقات العسكرية تحتاج الى نماذج ألارتفاع الرقمية (DEMs) ذات قابلية تحليل عالية (High Resolution) ومتوفرة محلياً وعالمياً. لحسن الحظ, التقدم الحاصل في تكنلوجيا الفضاء وفرت لنا صورة فضائية منفردة (ليست مجسمة) ذات قابلية تحليل عالية (تقريباً لكل العالم) يمكن أن تستخدم لزيادة كثافة النقاط لنموذج ألارتفاع الرقمي (بمعنى أخر, زيادة قابلية تحليل النموذج). تماشياً مع هذا التوجة فأن البحث تتناول أنتاج النموذج الارتفاع الرقمي من خارطة طوبوغرافية مقرؤة ضوئياً ومن ثم تحسين قابلية تحليل نموذج ألارتفاع الرقمي باستخدام صورة فضائية منفردة.

INTRODUCTION

DEMs are used for the analysis of topographical features in GIS and numerous engineering computations as well as scientific applications. Digital Elevation Models (DEMs) are simply regular grids of elevation measurements over the land surface. DEMs are mainly extracted by applying the technique of stereo measurements on images available from photogrammetry and remote sensing [Allam, 1978].

A GIS is a technology which can be used for scientific investigations, resource management, and development planning. Broadly speaking, a GIS consists of four different components: - 1) data collection, 2) data storage, 3) data analysis and processing, and last but not least 4) information retrieval. Among many types of data, Digital Elevation Models (DEMs) as well as remote sensing play a key part in the development of GIS [Khalaf, 2004].

Today, with the need for the better management of the limited natural resources, there are numerous geosciences and engineering applications which require denser DEM data than available. Unfortunately stereo satellite imagery is not available everywhere. Obviously, time and cost are two important factors that often prevent us from field measurements. While interpolation techniques are fast and cheap, they have their own inherent difficulties and problems, especially in terms of accuracy of interpolation in rough terrain [Rajabi, 2006].

On the other hand, the availability of single satellite imagery for nearly all of the Earth is taken for granted nowadays. This research paper was an attempt to explore the feasibility of enhancing the DEM interpolation accuracy using the reflectance data with single (as opposed to stereo) satellite imageries. The motivation for this investigation is the availability of relatively inexpensive but up to date, multiresolution, multispectral single satellite imageries for almost the whole world [Rajabi, 2006]. In this paper we will discusses generation of digital elevation models from scanned topographic map and spatial (resolution) enhancement by using single satellite imagery which is used as a main tool in this research.

Digital elevation model (DEM) is an important and interesting field for many engineering applications, as attested by the large volume of published literature. The relevant work may be summarized as follows:-

[Patrice Arrighi and Pierre Soille, 2007] presented a general methodology for the generation of digital elevation models (DEMs) starting from scanned topographic maps. they concentrate on the extraction and filtering of the contour lines from the input maps. This is a difficult problem due to the presence of complex textured backgrounds and information layers overlaid on the elevation lines (e.g., grid lines, toponymy, etc.). Results are presented on a wide variety of samples extracted from a (1:50000) plate scanned at 300 DPI.

[Makki A. 2007] presented a study to evaluate the most suitable and accurate interpolation method in producing digital elevation model for the data gathered from existed topographic maps which are also compared with data gathered from field survey. Different map scales (1:100000, 1:50000, 1:25000) with different contour intervals (50m, 10m, 5m) were chosen in the tests. The accuracy tests based on the National Mapping Accuracy Standards (NMAS) by comparing the result of Root Mean Square Error (RMSE) in elevations with the typical standard deviation (σz) proposed by (NMAS) which depends on the scale of maps and contour intervals. From testing four interpolation techniques ((Kriging, Triangulated Irregular Network (TIN), Inverse Distance Weighting (IDW) and Polynomial)) it was found that kriging is the best method followed by TIN method while IDW method failed in some tests, and the polynomial model failed in all tests.

[A. Rajabi, 2003] discusses the application of shape from shading (SFS) techniques to improve the quality of the interpolated DTM grid data with single satellite imagery of better resolution then the DTM data. The idea is highly motivated by the wide availability of satellite remotely sensed imagery such as Landsat TM and SPOT HRV imagery.

EXPREIMENTAL WORK

Study Area Site Description

The study area is a part of Chamchamal region in the northeast of Iraq, exactly in the northeast part of Chamchamal region. The study area is located on both sides of Tigris River. Chamchamal region bounded by the coordinate, it extends between latitudes (from 35^0 55' 00" to 36^0 00' 00") and longitudes (from 44^0 55' 00" to 45^0 00' 00") in zone 38N according to UTM cartographic coordinate system. Figure (1) shows the location of this region.

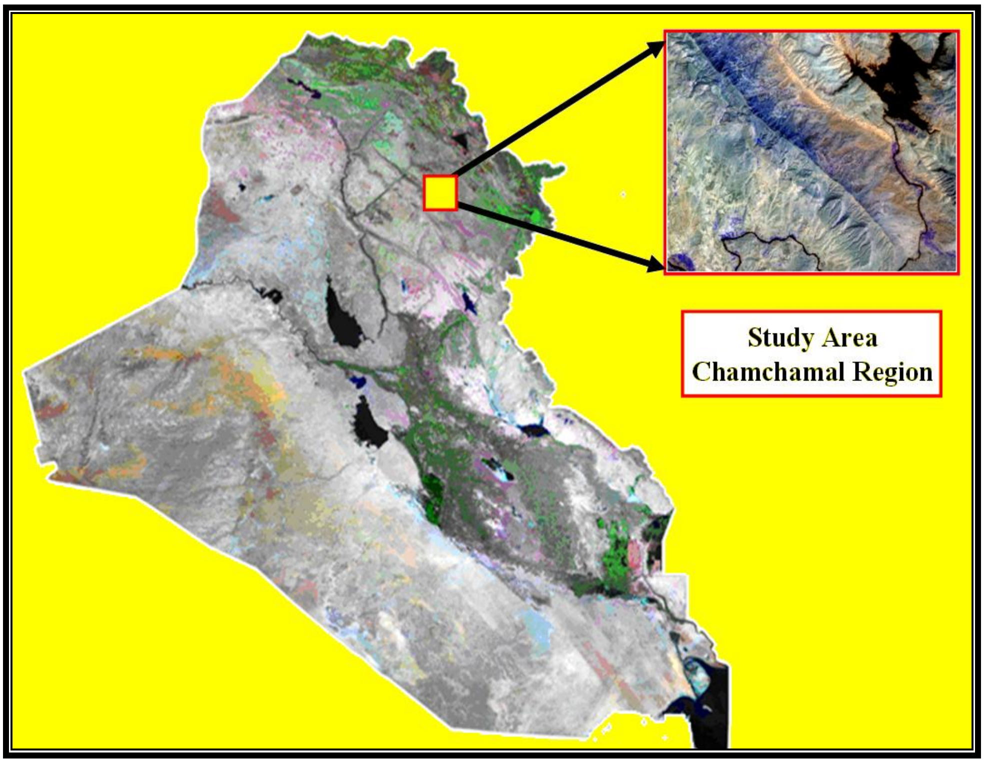

Fig. (1): Study Area (Chamchamal region).

Topographic Map Features

Topographic map with the following specification are used scale of (1:100,000) with contour interval of (50) meter, which was produced in general surveying directorate. The main features in the topographic map for study area are, Valleys and mountains is the most active features of land cover in the Chamchamal region due to high slopes of this region, also the Small Zap River passes through this region. This region is composed of many layers that covered the features in the topographic map. The terrain is generally not flat. Figure (2) shows the study area map.

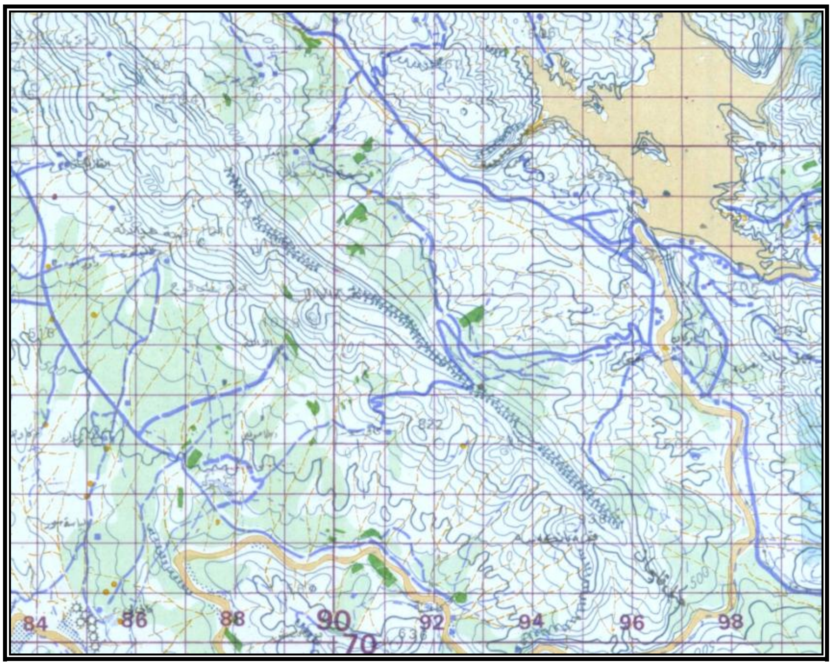

Fig. (2): Study Area (Chamchamal Map).

Characteristics of Satellite Image

Satellite image is Landsat 7 ETM+, which was acquired in September 2002. Satellite image with eight bands provided as eight image files with GeoTIFF extension, six represents multispectral band with spatial resolution of (30) meters, one represents panchromatic band with spatial resolution of (15) meters and one represents thermal band with spatial resolution of (60) meters. The satellite image is geometrically corrected with the following map properties, UTM projection, Clarke, spheroid (1880), and zone (38N) and unites in meters. Figure (3) shows satellite image of study area.

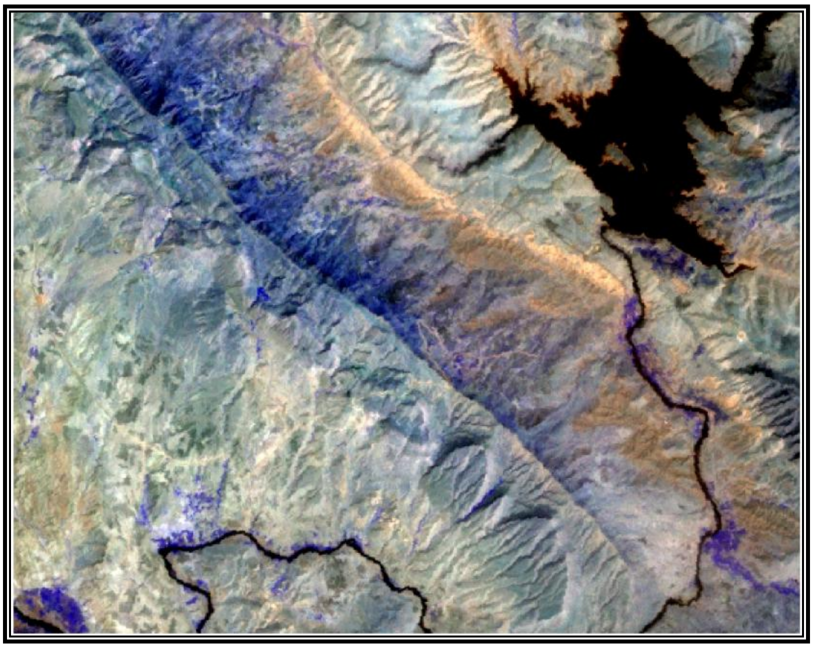

Fig. (3): Study Area (Chamchamal Satellite Image).

PRODUCTION OF DIGITAL ELEVATION MODEL FROM TOPOGRAPHIC MAP.

Extraction of Contour Lines

A contour is an imaginary line of constant elevation on the ground surface. If may be though of as the trace formed by the intersection of a level surface with the ground surface, for example, the shoreline of a still body of water [Anderson and Mikhail, 1998]. The semi-automatic digitization to the contour lines of the topographic map was done by using ArcMap package in ArcGIS version (9.1) by creating shapfile* (A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class [ESRI, 2002]) used for this purpose, with indicating for the value of each line. Understanding this step, with more details can be made from the illustration contour line layer which will be given in figures (4) of the study area.

Errors may result, when the contour lines are drawn. These errors are dependent on the regions (study areas) nature. When some of regions like (Chamchamal) includes high slopes (i.e. very high contour line density), the probability of obtaining errors is increased. These errors result from the cutting in the lines or the removing of the extra lines.

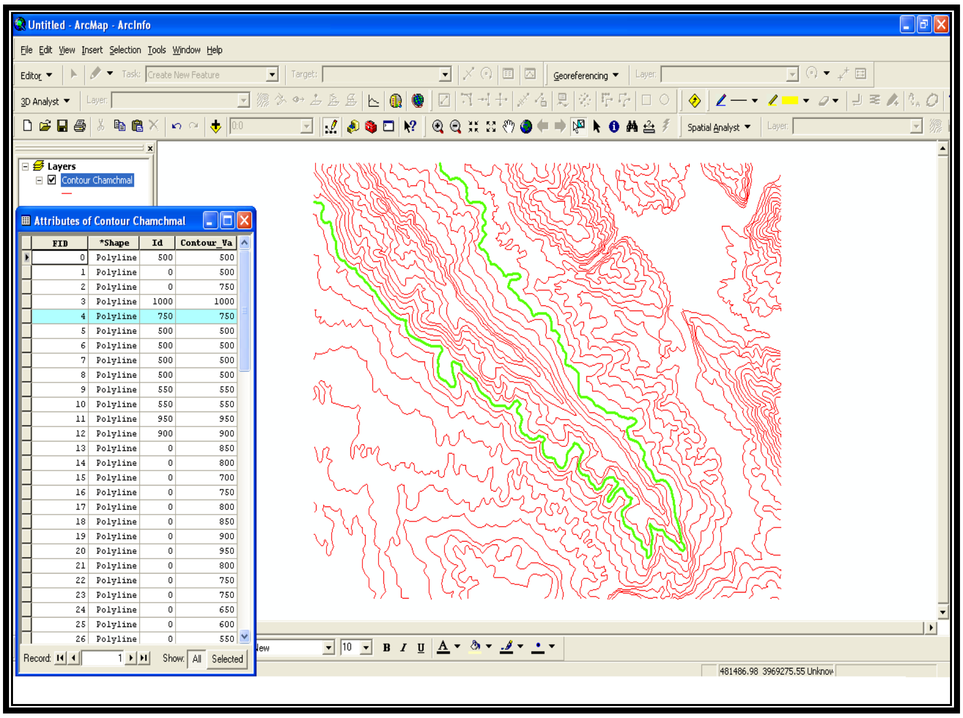

Fig. (4): Contour map of Chamchamal area with labled contours.

Building of Digital Elevation Model

The production of raster DEM from contour lines includes two steps: The first step is by creating the points as (X, Y and Z) coordinate from shapfile format by using ERDAS IMAGINE package. The ERDAS IMAGINE system incorporates the functions of both image processing and GIS. These functions include importing, viewing, altering and analyzing raster data and vector data sets [ERDAS, 1999]; these points are then exported as text file with (.txt) extension. The second step is creating surface (DEM) from these points, It is then so easy to open the text file format (with .txt extension) in text editor and save it as ASCII data file format (with .dat extension) in ERDAS IMAGINE Package. The ASCII data file is used to create a surface represented as Digital Elevation Model (DEM). The raster image format (DEM) with (.IMG) extension. This process is called surfacing in ERDAS IMAGINE package. This surface was decided to consist of (1092) points as (X, Y and Z), the output cell size (resolution) (100*100) m^2. After that the digital elevation model is displayed as a perspective view as shown figure (5).

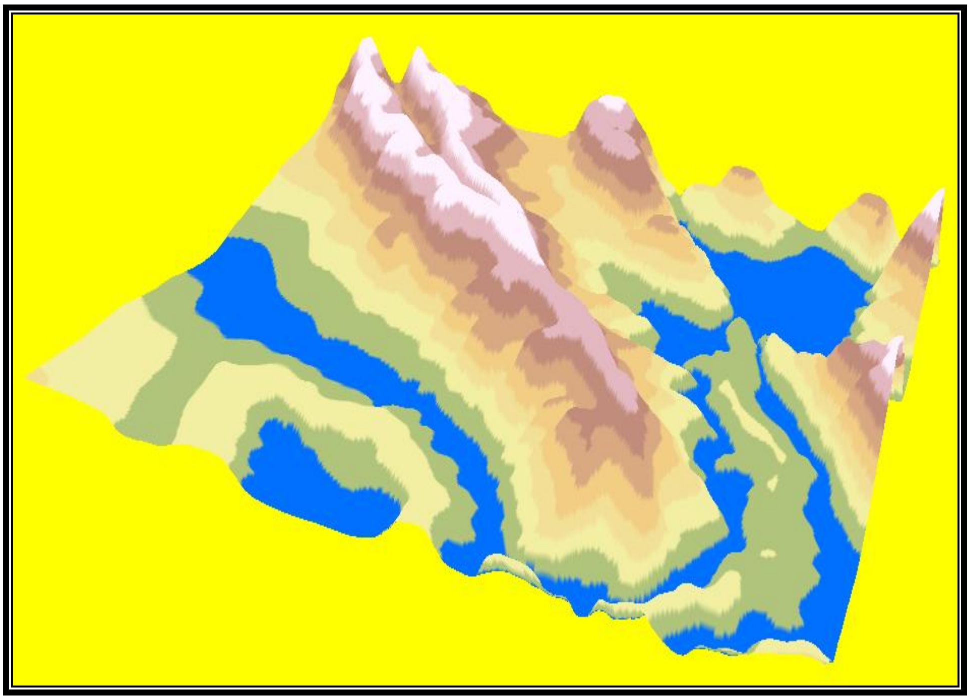

Fig. (5): 3D view of the produced DEM.

RESOLUTION ENHANCEMENT OF DIGITAL ELEVATION MODEL

After the production of the digital elevation model (DEM) from topographic map, the elevation values (Z coordinates) were computed in a regular grid (100 meter grid spaces). The main goal of this study is to improve the accuracy (resolution) of DEM grid data by using single satellite imagery (i.e. the elevation values (Z coordinates) will be computed in a regular grid (30 meter grid spaces).

Satellite Image Classification

The purpose of classification is to extract information from image. Information will be transferred to separate raster layers, each layer represent a type of land cover and/or land use. The results of digital image classification include unsupervised classification results that represent the two approaches used to classify the raw data. In this study we choose unsupervised method to classify the satellite image, because no extensive prior knowledge of the region is required, the opportunity for human error is minimized and unique classes are recognized as distinct units [Gonzalez, 1992].

Unsupervised Classification

The purpose of classification is to extract information from image. Information will be transferred to separate raster layers, each layer represent a type of land cover and/or land use. The results of digital image classification include unsupervised classification results that represent the two approaches used to classify the raw data.

One of the most unsupervised classification methods is the ISODATA, whose algorithms calculate class means evenly distributed in the data space and then iteratively cluster the remaining pixels using minimum distance technique (The minimum distance decision rule also called spectral distance) calculates the spectral distance between the measurement vector for the candidate pixel and the mean vector for each signature [ERDAS, 1999].

The unsupervised classification operation was performed. In this study we classified the satellite image with six spectral classes. From six classes we choose three classes for propose this study. Figures (6) show the results of these operations with a summarized explanation for each class based on ground truth information. The figures show that for trial, the unsupervised classification technique gives good representation of some classes and merges among others, and this method may categorizes some classes into more than one spectral class (such as streets and soil, streets and vegetation, and soil and vegetation). This may be attributed to many reasons such as the difference in the type density and its non homogeneity, sensor resolution, sensor angle of view, and the sun's altitude angle.

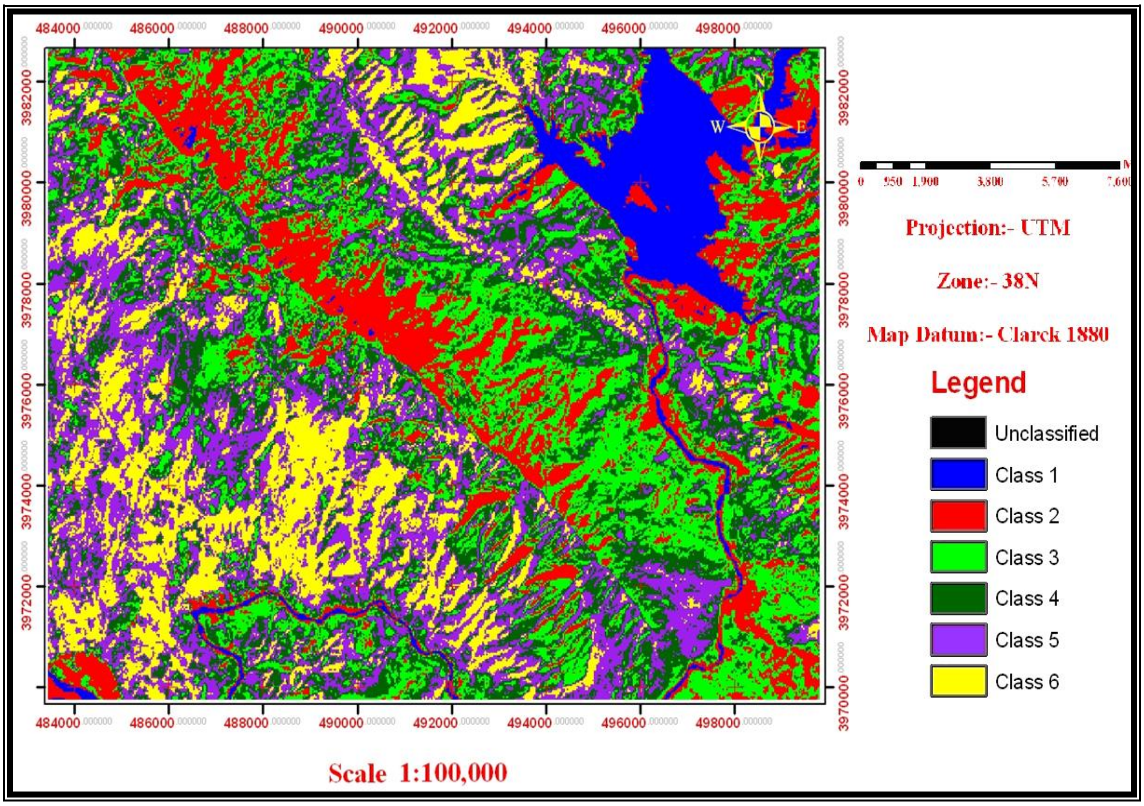

Fig. (6): Classification of Satellite image.

CONVERTING THE DIGITAL NUMBER TO REFLECTANCE

Obviously, any band from satellite image consist of number of cells is called pixels, each pixel also has a numerical value, called a digital number (DN) that records the intensity of electromagnetic energy measured for the ground resolution cell represented by that pixel [Gonzalez, 1992]. For satellite (Landsat) data, there is often need to calculate radiances from the digital values and calculate reflectance from radiances provided as image data, usually because specific analyses require radiances or because it is necessary to compare data from one scene to another illustrated in figure (7). The DN images are converted first to at satellite radiance and then to at satellite reflectance using the following equations [USGS, 2001].

$$L\lambda = (Gain\lambda * DN\lambda) + Bias\lambda \quad \text{.......................................} (2.1)$$

$$\rho\lambda = (\pi * L\lambda * d2) / (ESUN\lambda * \sin(\theta)) \quad \text{.......................................} (2.2)$$

Where:-

λ = ETM+/TM band number.

L = At-satellite radiance.

Gain = Band specific, provided in the header file.

Bias = Band specific, provided in the header file.

ρ = At-satellite reflectance, unit less.

d = Earth-Sun distance in astronomical unit. The Earth-Sun distance can be derived from table (2.3).

ESUN = Solar exoatmospheric spectral irradiance from table (2.2).

θ = Sun elevation angle

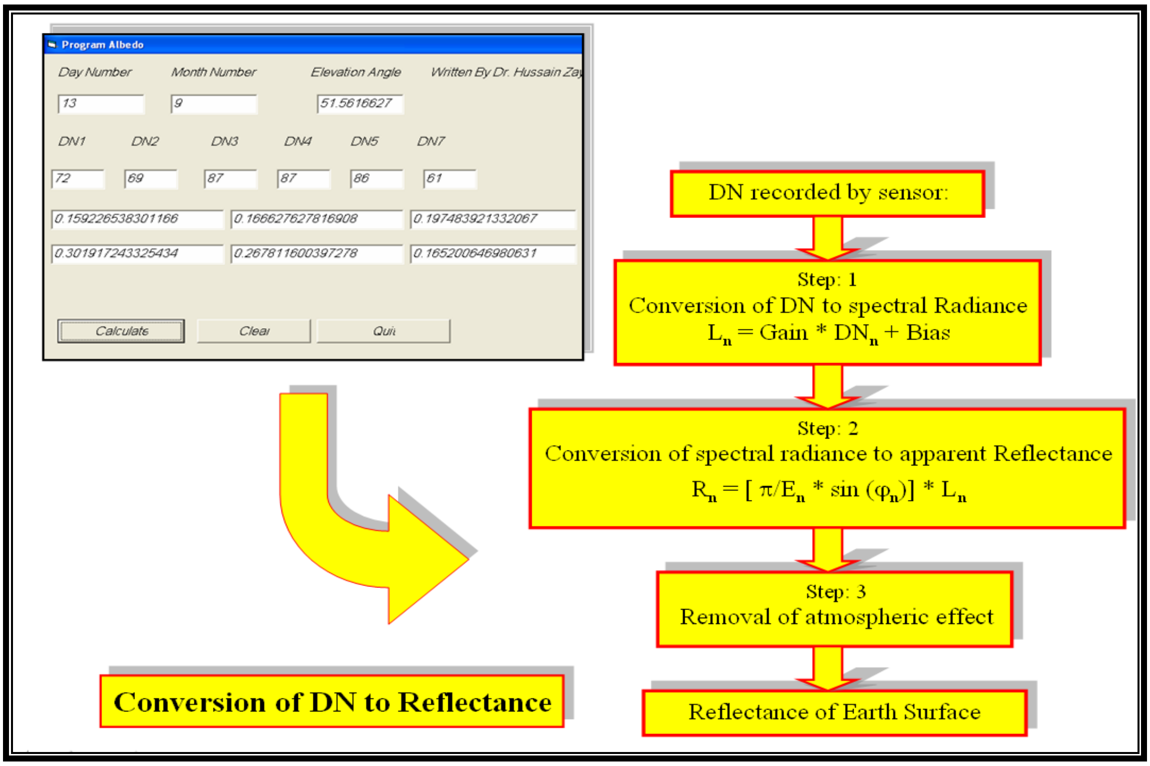

Figure (7): Reflectance Values Calculation.

Table (2.2): ESUN Solar Spectral Irradiances [USGS, 2001].

Band	L7 ETM+	L5 TM
1	1969.000	1957.000
2	1840.000	1826.000
3	1551.000	1554.000
4	1044.000	1036.000
5	255.700	215.000
6	82.070	80.670
7	1368.000	

Table (2.3): Earth-Sun Distance in Unit [USGS, 2001].

Julian Day	Distance	Julian Day	Distance	Julian Day	Distance
1	0.9832	121	1.0076	242	1.0092
15	0.9836	135	1.0109	258	1.0057
32	0.9853	152	1.0140	274	1.0011
46	0.9878	166	1.0158	288	0.9972
60	0.9909	182	1.0167	305	0.9925
74	0.9945	196	1.0165	319	0.9892
91	0.9993	213	1.0149	335	0.9860
106	1.0033	227	1.0128	349	0.9843
				365	0.9833

In this study we convert the digital number to reflectance value. However, we used code (program) in Visual Basic language to extract reflectance value. This program uses data obtained from Landsat 7 ETM+ raw image with six bands (1, 2, 3, 4, 5 and 6) such as sun elevation, sun azimuth, exposure dated, earth sun distance and constants values for detectors found in Landsat 7 ETM+.

Densification of DEM Grid Data

After converting the digital number values for each band from classes to the reflectance values. Now we have classes consist from these bands, bands are in matrix form which holds the reflectance values. To densify the DEM grid data, it should be converting the reflectance values to elevations. The following steps are involved in the densification of DEM grid data.

The first step: subscribed points taken between a part from DEM (low resolution) and classes by using ERDAS IMAGINE package. This is process is called Geolink.

The second step: computing the best fitting (relationship) between the elevations (H) and spectral reflectance values (R) (i.e. high correlation coefficients and low residual error). The above processing was done by using statistical program called (Curve Expert (ver. 1.3)). This program it sifts through every possible curve fit. Ranks the fits from best to worst, and presents you with the best equation (high coefficients and low residual error) from (30) equations and the best fit is then displayed in the graphing window. The sinusoidal fitting (y=a+b*cos(c*x+d)) were the best fitting in this tests. But found simple difference by correlation coefficient, residual error and coefficients from fitting to fitting another. Table (1) shows the parameter of fitting for each class, figure (8) shows the best equations chosen for classes by using Curve Expert (ver. 1.3) package.

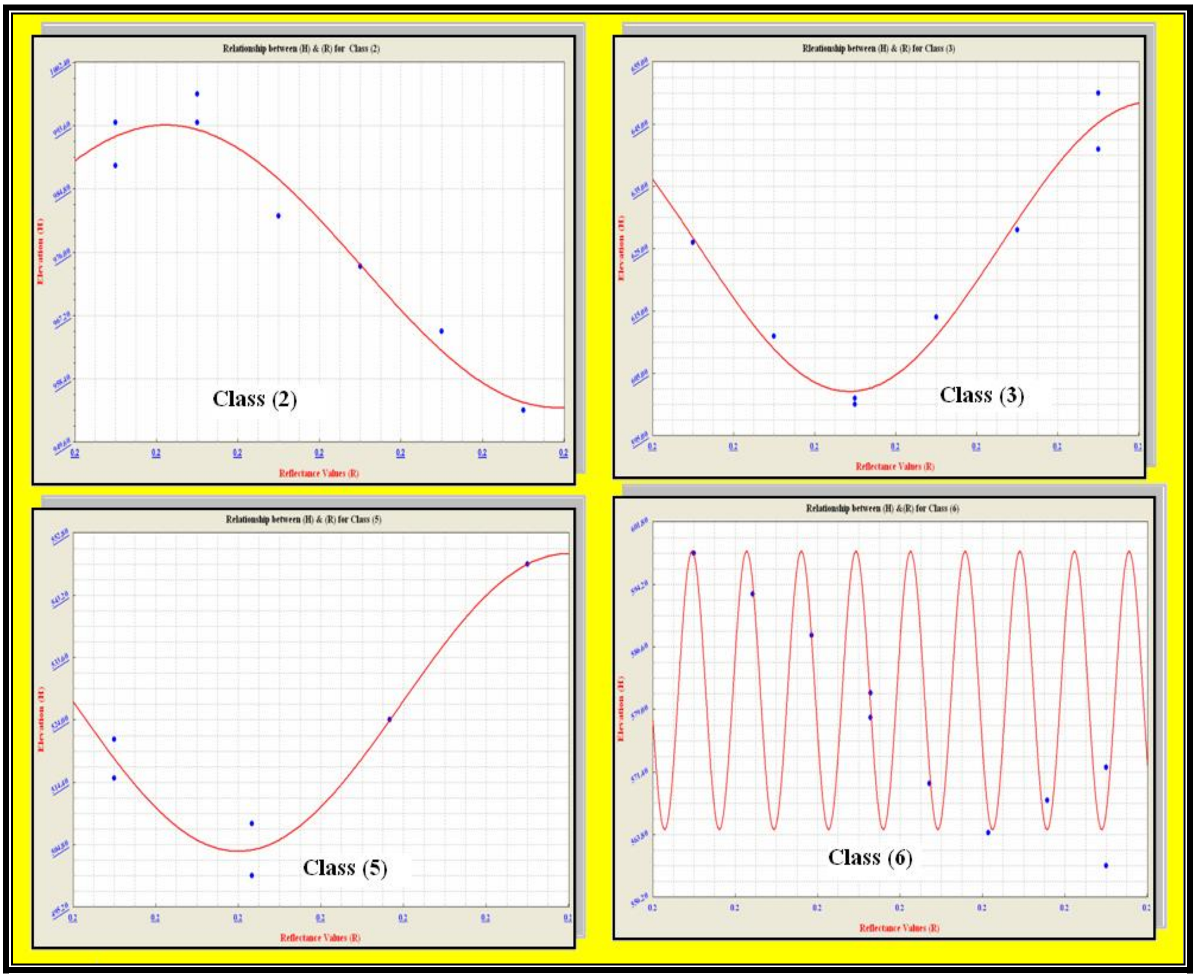

Fig. (8): Relationship between Elevation and Reflectance Values for the Classes (2,3,5 and 6).

Table (1): Parameter of the Sinusoidal Fitting for each Class.

NO. of Classes	Coefficients				Correlation Coefficient	Residual Error
	a	b	c	d		
2	974.013	19.638	272.371	-22.959	0.9759728	4.505158
3	625.306	23.226	353.602	-16.740	0.9862825	3.961472
5	523.538	9.7274	505.751	4.66391	0.9448530	3.904637
6	581.322	16.933	2827.56	33.7233	0.9652660	4.058228

The third step: After computing the best fitting (relationship) between the digital elevation model (low resolution) and classes. We converted each reflectance values (R) to elevation (H) and then we give (X, Y) coordinates for each elevation. The above processing was done by using MATLAB.

The fourth step: It is then so easy to open the text file format (with .txt extension) in text editor and save it as ASCII data file format (with .dat extension) in ERDAS IMAGINE Package. The ASCII data file is used to create a surface represented as Digital Elevation Model (DEM) [ERDAS, 1999]. The resulted DEM is geometrically corrected. This surface is consist of Enormous points (as X, Y & Z), the output cell size (resolution) (30*30) m^2. In figure (9) the results of DEM spatial (resolution) enhancement by using single satellite image data were satisfactory, as revealed by the RMSE obtained. These results suggest, first, that single satellite image gives a high resolution better than from the digital elevation model (DEM) which is obtained from scanned topographic map, second, that single satellite image is multispectral, third, that of the method used in this study are appropriate for this type of data and this area.

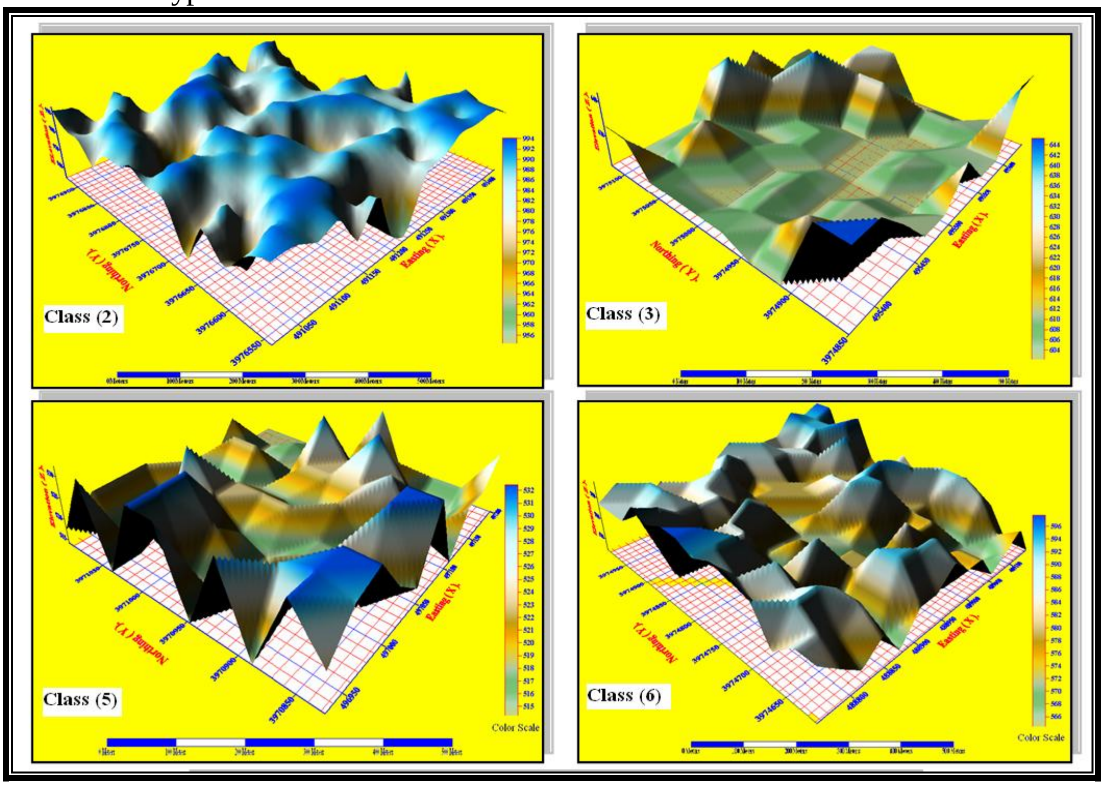

Fig. (9): Raster DEM after Resolution Enhancement for Classes.

THE EVALUTION OF ACCURACY FOR DIGITAL ELEVATION MODEL

After producing the digital elevation model from the scanned topographic map and after resolution enhancement of digital elevation model by using single satellite image, the models are transferred to (Raster Digital Elevation Model). Thirty well distributed the find DEM points were chosen on the transferred model and its coordinates were recorded (E, N AND Elev.) then projecting them the topographic map which are related to the same model, using the value of elevation by traditional methods and taking in consideration the distance between the two lines, the point lies between them and the contour interval value, then computing the value of (RMSE) in elevations with the typical standard deviation proposed by National Mapping Accuracy Standard (NMAS) depending on the used map scale and contour interval (See Table (2)). The resulting accuracy of digital elevation models (high resolution) was found to be the best from accuracy for digital elevation model produced previous from scanned topographic map.

Table (2): The Computed Standard Deviation of DEM for the Study Area.

NO.	Type of Error	Results	
		Raster DEM Before Resolution Enhancement	Raster DEM after Resolution Enhancement
1	Computed Standard Deviation	3.161 m	2.814 m

CONCLUSIONS

- The digital elevation model (DEM) produced from scanned topographic map by using simple automatic method were compared on the basis of computing the root mean square error (RMSE). It was found that the proposed method gives improved results. Generally, the scale of map and the contour interval affect the accuracy of the produced digital elevation model (DEM).

- Although the densification process for grid data gives a good results in digital elevation model (DEM) in this study, but cannot be adopted for large areas, because it is limited. Other conditions and constrains must be taken to over come this limitation. It is obvious there is no fixed relationship between the elevations and spectral reflectance values.

- The use of large scale topographic map (1:10000, 1:5000, 1:1000 …) with small contour interval (10, 5) for production of digital elevation model (DEM).

- The use of modern software which automatically converts contour maps from its raster format into vector format like (ArcScan) software in a process called vectorization.

- Using raw satellite images of high resolution (from one meter to five meter) such as those from SPOT or IKONOS satellites, and use multispectral image with high spectral resolution to extract more information from satellite image.

- It is preferred to use the field survey is very essential and important to notice the variance among the soil classes, to obtain and fix the ground truth throughout the laboratory tests and to determine earth covers classes.

- 5- It is preferred in future work to use supervised classification method, because supervised classification method gives good presentation of the classes with overall accuracy (for training regions) equal to (96%).

- Use the shape from shading (SFS) to densification of digital elevation model (DEM) grid data.

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LIST OF ABBREVIATIONS

DEM: Digital Elevation Model.
DEMs: Digital Elevation Models.
DN: Digital Number.
ERDAS: Earth Resources Data Analysis System.
ETM+: Enhanced Thematic Mapper +.
GIS: Geographic Information System.
GeoTIFF: Geographic Tagged Image File Format.
ISODATA: Iterative Self Organizing Data Analysis.
Landsat: Land Satellite.
NMAS: National Mapping Accuracy Standard.
RMSR: Root Mean Square Error.
UTM: Universal Transverse Mercator Projection.
VMAS: Vertical Map Accuracy Standard.