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3D Building Reconstruction Using DEM and Mosaic Model

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Abstract

A digital elevation model (DEM) is a digital representation of ground surface topography or terrain. It can be represented as a raster (a grid of squares) and it is commonly estimated by utilizing remote sensing techniques, or from land surveying. In this research a 3D building of Baghdad university campus have been performed using DEM, where the easting, northing, and elevation of 400 locations have been obtained by field survey using global positioning system (GPS). The image of the investigated area has been extracted from QuickBird satellite sensor (with spatial resolution of 0.6 m). This image has been geo-referenced by selecting ground control points of the GPS. The rectification is running, using 1st order polynomial transformation. Estimation of the ground layer elevation is carried out by spline and IDW interpolation, the buildings have been delineated as polygons with given real heights in the second layer. The mosaic algorithm has then been applied between the two layers to perform the final DEM creation process. Finally, the estimated DEM have been used to constructing 3-D building.

Keywords: DEM, IDW, spline, mosaic.

تصميم بنائية ثلاثية الابعاد باستخدام نموذج الارتفاع الرقمي والفسيفساء

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الخلاصة

نموذج الارتفاع الرقمي هو تمثيل رقمي لتضاريس سطح الارض. ويمكن تمثله على شكل صورة رقمية وهو بصورة عامة يمكن حسابه باستخدام تقنيات التحسس النائي او استخدام المسح الجغرافي. في هذا البحث تم استخدام نموذج الارتفاع الرقمي لتصميم ثلاثي الابعاد لبنائية مجمع جامعة بغداد، حيث تم جمع احداثيات الشرق والشمال لاربعمائة نقطة بواسطة المسح الميداني بجهاز نظام التموضع العالمي GPS كما تم استخدام صورة ذات دقة عالية بحدود 0.6m مأخوذة بالقمر الصناعي quick-bird حيث تم ترقيم هذه الصورة باختيار نقاط ارضية مقاسة الـ GPS وتطبيقها لتعديل الصورة بواسطة التحويلات الخطية من الدرجة الاولى. تم تحويل بيانات الصورة الى طبقتين الطبقة الارضية التي طبقت عليها تقنيات الاستكمال الثنائي مثل IDW, SPLINE والطبقة الثانية هي طبقة البنائيات التي حددت ارتفاعاتها الحقيقية هندسيا باستخدام الشكل

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الرباعي. بعد ذلك تم دمج الطبقتين باستخدام نموذج الفسيفساء mosaic لتخمين الشكل النهائي لنموذج الارتفاع الرقمي الذي استخدم لتصميم الشكل الثلاثي الابعاد لمنطقة الدراسة.

1. Introduction

A digital elevation model (DEM) is a digital file of terrain elevations for ground positions. It is a raster representing the elevation of the ground and objects, such as buildings and trees, with pixel values in the images [1]. The result is a Digital Elevation Model (DEM). This allows for production of a variety of maps that range from straight topographic ones to those with specialized displays such as shaded relief maps and perspective maps. The DEM database can also be "wrapped over" a remote sensing image (equivalent points registered) to produce views that give a 3-D appearance (usually from a perspective or oblique view) to the natural landscape or manmade features in an image. Traditionally, DEMs may be generated by either ground surveying, from existing contour maps, by photogrammetric analysis of stereo aerial photographs, or more recently by automated analysis of stereo satellite data, [2]. In fact, elevation data that are derived from field survey operations provide the most accurate method of obtaining data. This is done by physically taking measurements along a grid of positions on the ground. The measurements obtained during the field survey are either input directly into computer systems through data recorders coupled to field instruments or subsequently stored in a digital form. Accordingly, in this project, the field survey operation has been adopted to collect the data (i.e. Easting, Northing, and Elevation), using GPS navigators. Many interpolation method have been used to estimate the elevation such as spline and IDW, georeference, rectification and mosaic model will be illustrated in this research.

2. Interpolation methods

There are several interpolation methods. Each method calculates grid node values using a different algorithm, these methods can be detailed as bellow.

2.1 Inverse Distance weighted

Inverse Distance Weighted (IDW) is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight; it has in the averaging process. The Power parameter controls how the weighting factors drop off as distance from a grid node increases. For a larger power, closer data points are given a higher fraction of the overall weight; for a smaller power, the weights are more evenly distributed among the data points.

The weight given to a particular data point when calculating a grid node is proportional to the inverse of the distance to the specified power of the observation from the grid node. When calculating a grid node, the assigned weights are fractions, and the sum of all the weights is equal to 1.0. When an observation is coincident with a grid node, the observation is given a weight of essentially 1.0.

This method basically depends on estimating the height of the unknown point by computing the distances from this point to the other known points. Weights are proportionally by inverse to distances; i.e. whenever the point being far away, its effect reduce, and the following equation explain it, [3, 4].

$$Z(X, Y) = \frac{\sum_{i=1}^n \left[\frac{Z_i}{d_i^p} \right]}{\sum_{i=1}^n \left[\frac{1}{d_i^p} \right]} \quad (1)$$

$$Z(X, Y) = \sum \lambda_i \cdot Z_i \xrightarrow{\text{With}} \sum \lambda_i = 1 \quad (2)$$

Where: d_i is the plan metric distance between the reference point and the i^{th} interpolation point; i.e.

$$d_i = \sqrt{(X_i - X)^2 + (Y_i - Y)^2} \quad (3)$$

Where: $Z(X, Y)$ is the predicted value at the ensample location X, Y .

n : is the number of measured sample points within the neighborhood defined for X, Y . Z_i : is the observed value at location i . λ : is the distance-dependent weight associated with each sample point.

d_i : is the distance between the prediction location X,Y and the measured location i . p : is the power parameter that defines the rate of reduction of the weight as distance increases .

2.2 Spline Interpolation

The Spline method is an interpolation method that estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. Conceptually, the sample points are extruded to the height of their magnitude; spline bends a sheet of rubber that passes through the input points while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This method is best for generating gently varying surfaces such as elevation, water table heights, or pollution concentrations. There are two Spline methods: Regularized and Tension. The Regularized method creates a smooth, gradually changing surface with values that may lie outside the sample data range. The Tension method controls the stiffness of the surface according to the character of the modeled phenomenon. It creates a less smooth surface with values more closely constrained by the sample data range. The basic form of the minimum curvature Spline interpolation imposes the following two conditions on the interplant:

- The surface must pass exactly through the data points.
- The surface must have minimum curvature—the cumulative sum of the squares of the second derivative terms of the surface, taken over each point on the surface must be a minimum.

The basic minimum curvature technique is also referred to as thin plate interpolation. It ensures a smooth (continuous and differentiable) surface, together with continuous first-derivative surfaces. Rapid changes in gradient or slope (the first derivative) may occur in the vicinity of the data points; hence this model is not suitable for estimating second derivative (curvature). The Spline function uses the following formula for the surface interpolation:

$$s(x, y) = T(x, y) + \sum_{j=1}^N \lambda_j R(r_j) \tag{4}$$

where : $j = 1, 2, \dots, N$. N : is the number of points. λ_j : are coefficients found by the solution of a system of linear equations. r_j : is the distance from the point (x,y) to the j^{th} point. $T(x, y)$ and $R(r_j)$: are defined differently, depending upon the selected option.

- For the **Regularized** options: $T(x, y) = a1 + a2x + a3y$

$$R(r) = \frac{1}{2\pi} \left\{ \frac{r^2}{4} \left[\ln\left(\frac{r}{2\tau}\right) + c - 1 \right] + \tau^2 \left[k_o\left(\frac{r}{\tau}\right) + c + \ln\left(\frac{r}{2\pi}\right) \right] \right\} \tag{5}$$

- for the **Tension** options: $T(x, y) = a1$

$$R(r) = -\frac{1}{2\pi\phi^2} \left[\ln\left(\frac{r\phi}{2}\right) + c + k_o(r\phi) \right] \tag{6}$$

Where: ϕ^2 and τ^2 : are the parameters entered at the command line.

r : is the distance between the point and the sample. k_o : is the modified Bessel function. C : is a constant equal to 0.577215. are coefficients found by the solution of a system of linear equations. For computational purposes, the entire space of the output raster is divided into blocks or regions equal in size. The number of regions in x and in y directions are the same and they are rectangular in shape. The number of regions is determined by dividing the total amount of points in input point dataset by the value specified for the number of points. For data less uniformly distributed, the regions may contain a significantly different number of points, with the value for the number of points being only the rough average. If in any region the number of points is smaller than eight, the region is expanded until it contains a minimum of eight points, [5, 6].

3. Study Area and Available Data

The Easting , Northing and elevation of 400 points located on the base and buildings of the studied area which represented by Baghdad university have been navigated using GPS survey, with UTM projection and world geodetic system (WGS-84), studied area can be shown in Figure-1 and its information can be seen in Table -1. In general, remotely sensed images are gathered by a satellite or

aircraft represent the irregular surface of the Earth. Even images of seemingly flat area are distorted by both the curvature of the Earth surface and the sensor being used. Different polynomials may be used to convert the source image's coordinates to the rectified map's coordinates. Number of the utilized GCPs as listed in Table-2 used depends on the distortion in the imagery. Since the covered area in this project (i.e. Baghdad University Compass) is not too large (can be covered by small size satellite image), thus the 1st order polynomial (affine transform) was found to be too efficient for the rectification process.

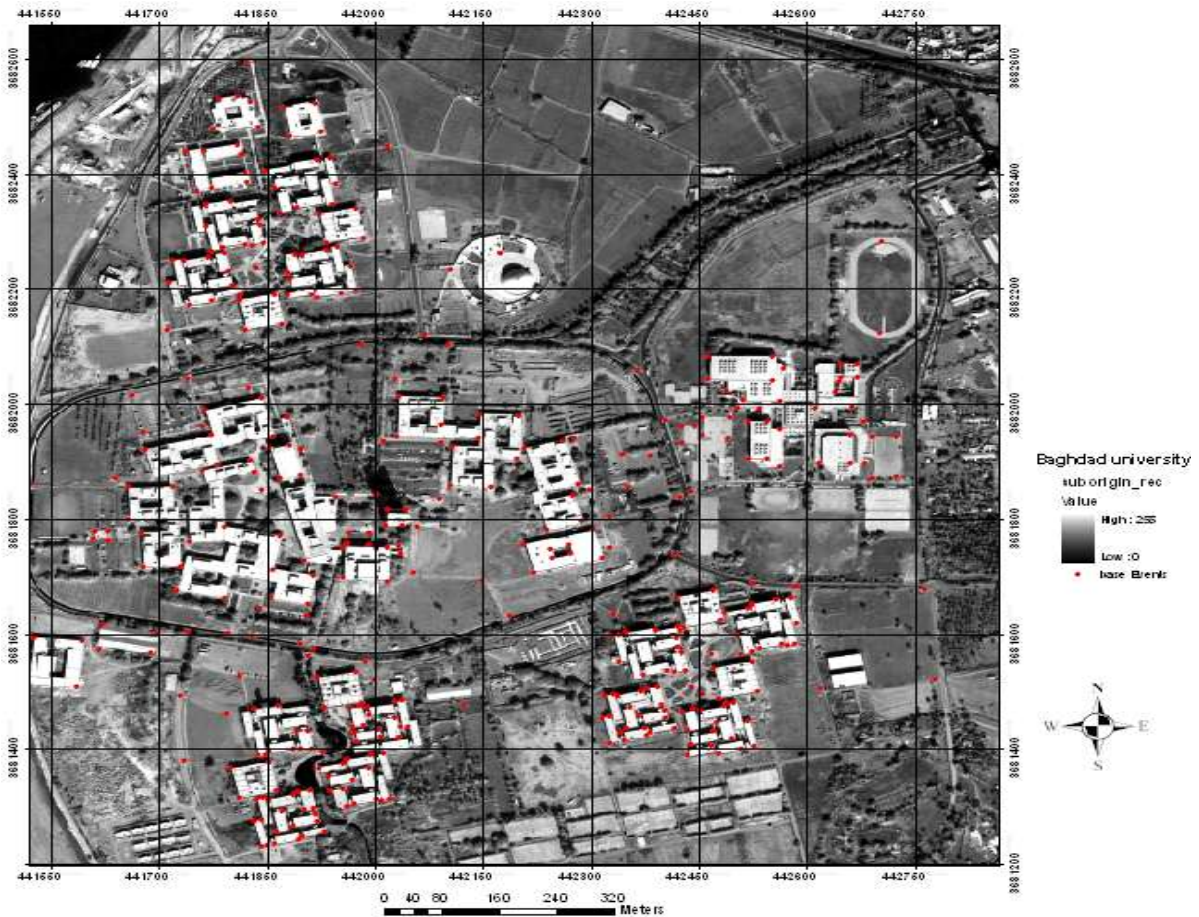


Figure1-point distributed on a rectified QuickBird Satellite (0.6m) image of the studied area.

Table 1- Represent the studied area information.

Raster information		Extent and Statistics		Spatial reference	
Columns	2915	Top	3682738.341 N	Linear unit	Meter
Rows	2615	Left	441331.590 E	Angular unit	Degree(.017453)
No. of band	1	Right	443095.699E	False_Easting	500000
Cell size(x, y)	0.6 m	bottom	3681155.787 N	False_Northing	0
		Min.	0	Central_meridian	45
		Max.	255	Datum	WGS_1984
		Mean.	136.951	Projection	UTM
		Std.dev.	63.576	Zone	38N
				Satellite	QuickBird

Table2-Measured GCPs points by GPS navigator.

GCP _s #	Easting	Northing
1	442302.30	3681780.75
2	441956.88	3681751.77
3	441945.61	3681838.38
4	441974.49	3681534.80
5	441800.48	3681367.29
6	441526.78	3681594.31

4. Methodology

Many DEM's creation models can be utilized to create the DEM's of the interested region; e.g. Inverse Distance Weighted (IDW), and the Spline models. The procedure of this research is depended on the following steps.

Step one: Slicing the utilized image information into two layers, the first representing the height building features, while the second representing the ground level features. Both the sliced layers should be georeferenced individually.

Step two: In order to simulate the topography of the ground-level, the previously mentioned interpolation methods; i.e. IDW and Spline can be used as shown in Figure-2.

Step three: Utilizing the ArcGIS package facilities to produce polygons representing the height buildings in raster format.

Step four: Each produced polygon should assign height value; representing the elevation values. This stage has been accomplished, using special designed subroutines as shown in Figure-3

Step five: The final necessary step for creating the DEMs is performed by projecting the building height image layer on the ground-level image layer. Since both of these layers were georeferenced, thus; the easiest way for the projection is by implementing the Mosaicing operation. The output of mosaic model in this research give the final shapes of digital elevation model with high resolution, the results can be shown in the Figure-4.

5. Production 3-D Image

A DEM is used as a mean of 3-D terrain modeling; it serves as a basic source of information for deriving geo-spatial uniqueness. Currently, Digital elevation modeling (DEM) is one of the modern methods for representing the topographic surface of the terrain, (i.e., how the elevation of the ground surface is changing with position) [7].The geo-referenced image of the studied area can be projected on the produced DEM to represent a 3D view. Figures- (5, 6) demonstrating several 3D views, generated in different ways, utilizing different interpolation techniques.

6. Results Analysis

Several classic interpolation methods representing the most commonly used techniques in remotely sensing applications have been chosen and implemented in the research Generally. In this research the procedure was depend on slicing the area into two layers. The ground-level (i.e. base-level) has been manipulated by utilizing different interpolation techniques (i.e. IDW and spline). Whereas the building layer has been reclassified by assigning the geometric height recorded directly to polygon points. Then mosaic model consider to be good techniques for merging the two layers i.e. (building and ground layer) to get the final shape of the DEM for science college of Baghdad university. The geo-referenced image of the studied area can be projected on the produced DEM to represent a 3D view.

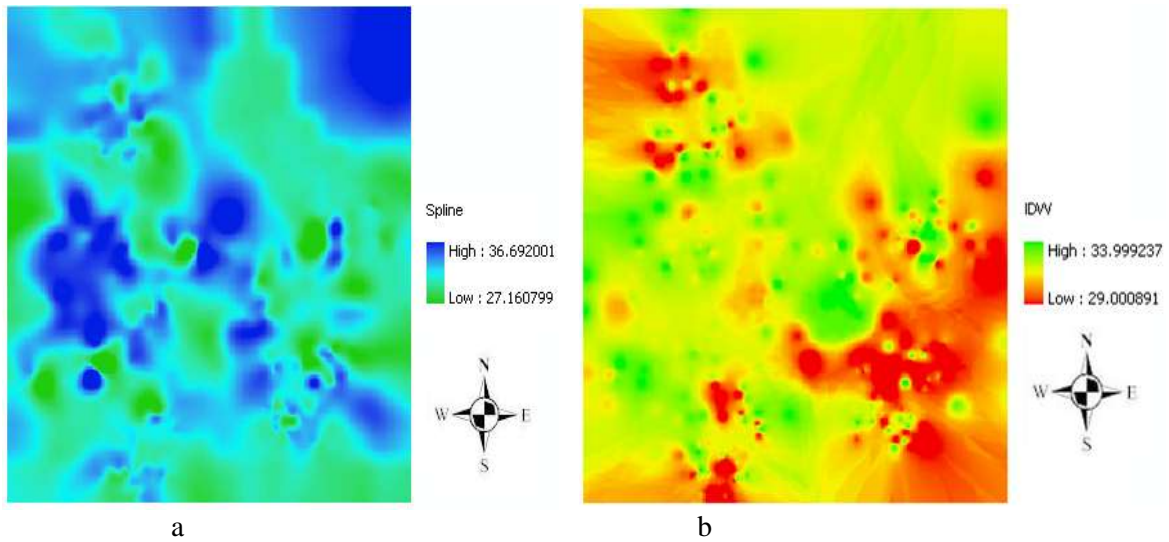
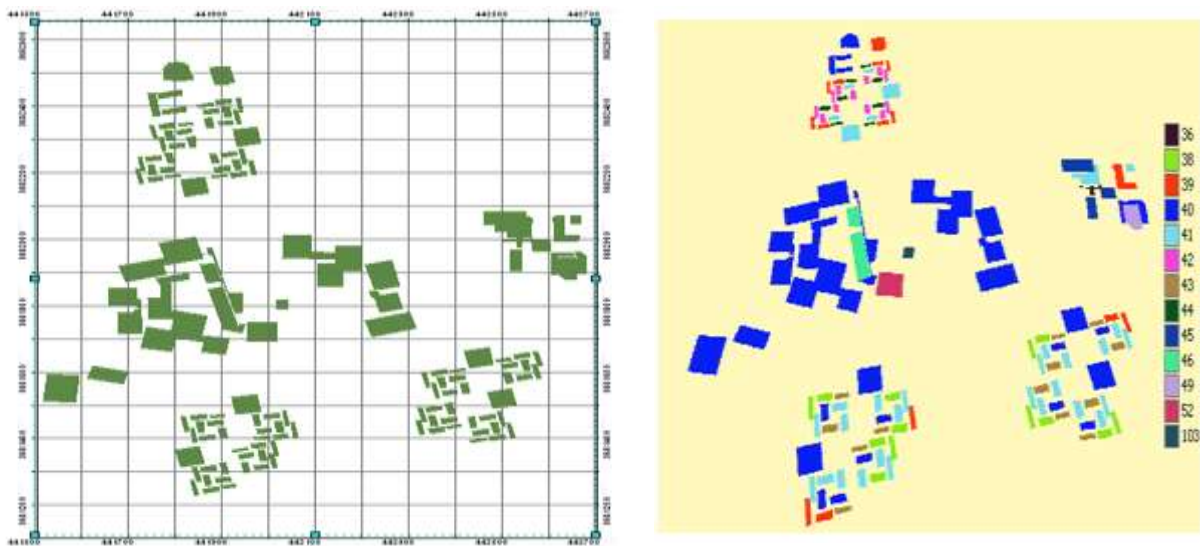
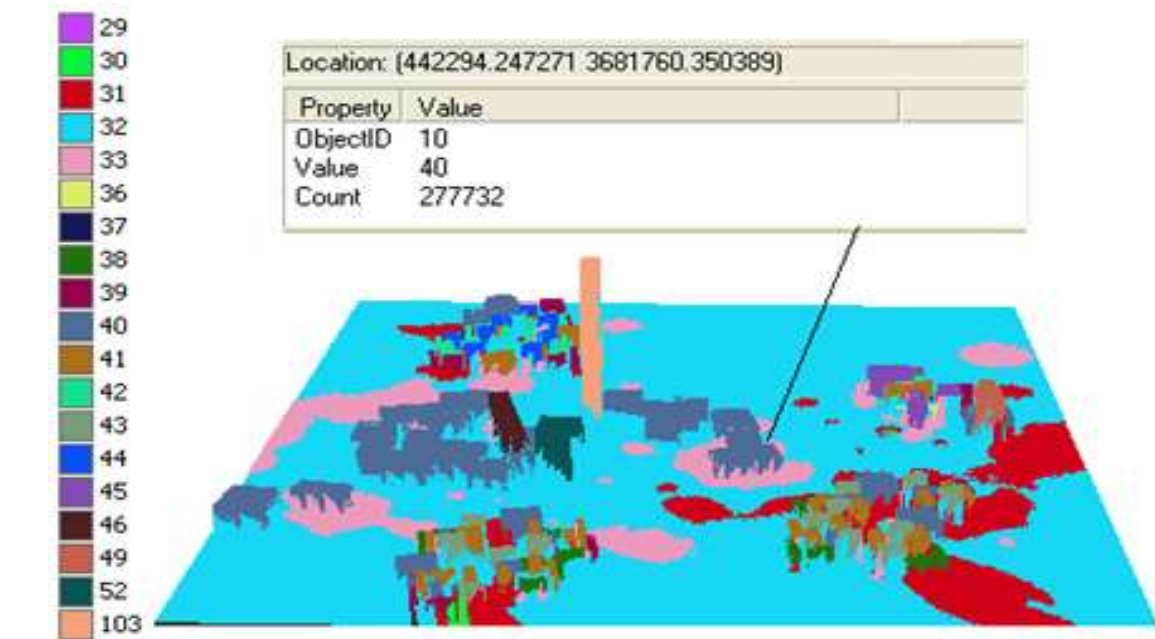
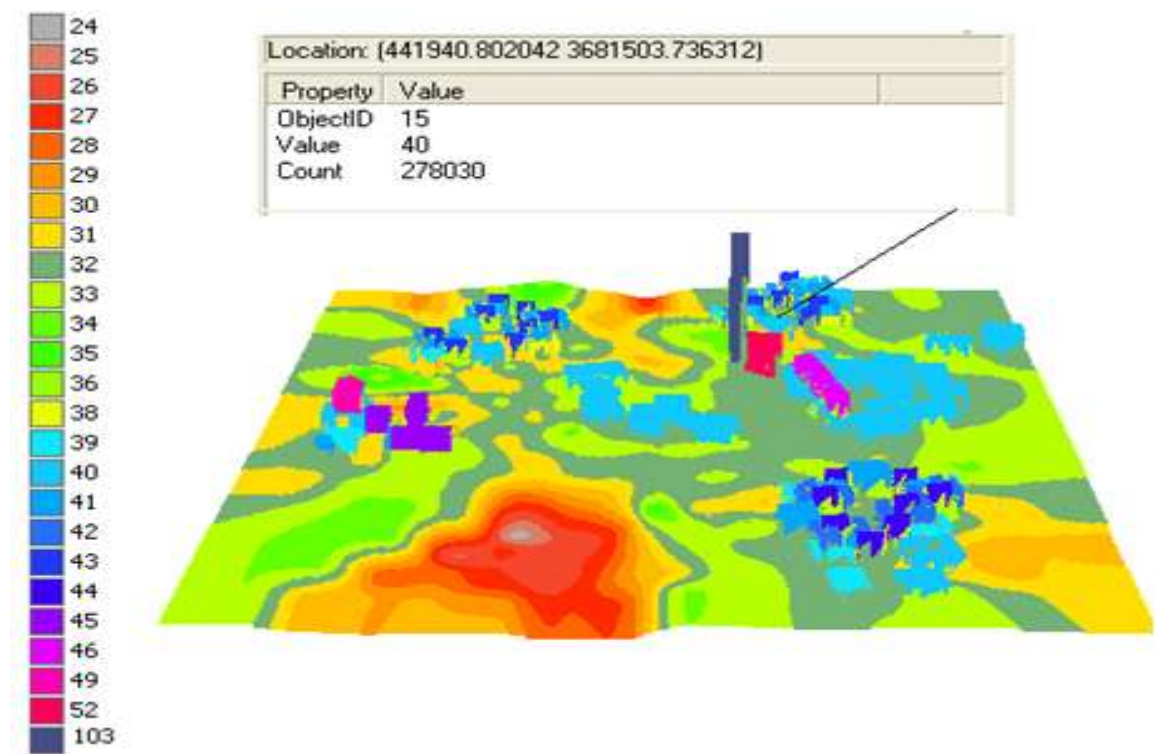


Figure 2- The raster DEM of the ground level slice, using a) spline, b) IDW interpolation.



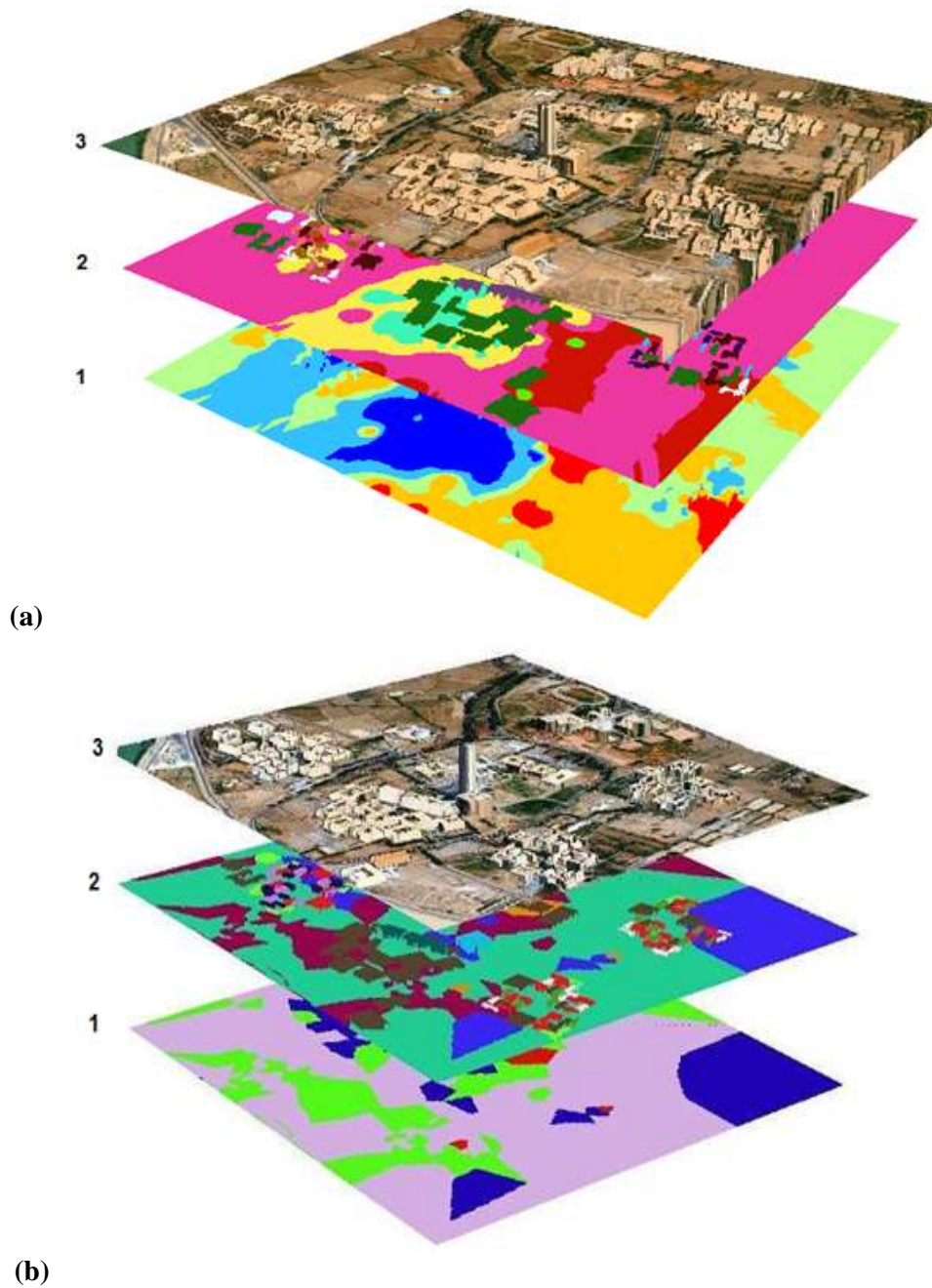


(a)



(b)

Figure 4- 3D-color view of final DEM estimated by a) IDW, b) Spline interpolation.



(b)
Figure 5-illustrating the generation of 3D view by projecting the image of the studied area on the layers of the, a) IDW, b) Spline interpolated levels (i.e. ground and buildings).



Figure 6-3D view of the building of the Baghdad university campus.

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