International Journal of Engineering & Technology, 7 (4.7) (2018) 250-253

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Experimental Analysis of Srtm Model by Image Processing and Geostatistical Methods

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Abstract

This article compares the image processing and geostatistical methods of GIS. They proposed the application of these methods to restore the quality of the well-known digital elevation model SRTM degraded sections using the example of the Krasnodar Territory. The conclusions are drawn also about the quality of modeling for test sites with different types of relief – flat, hilly and mountain. The best results were achieved for the method of bicubic interpolation.

Keywords: *Digital elevation model (DEM), geostatistics, image processing, kriging, SRTM.*

1. Introduction

Often it happens that the resolution of a satellite image or digital model is not enough to detail the objects of interest. Then there is the task of improving a raster image quality, which, in fact, is the problem of interpolation. As is known, it is solved by geostatistical methods [1].

The Geostatistical Analyst module is a revolutionary tool integrated into the GIS environment, as it helps to bridge the gap between geostatistics and geographic information systems. On the other hand, basic methods of interpolation in the image processing have also widely used in GIS.

The article presents a set of test data with degraded spatial resolution, processed by famous GIS ArcGIS 10.3 geostatistical and image processing methods of surface interpolation to restore the initial quality of SRTM model.

2. Test Site Selection

The popular and free available digital elevation model SRTM was chosen for analysis with initial spatial resolution of 90 m [2, 3]. Three detailed sites with a different type of relief were selected (Figure 1). Section 1 mostly has a flat relief, 2 - mountain relief, and 3 - hilly relief.

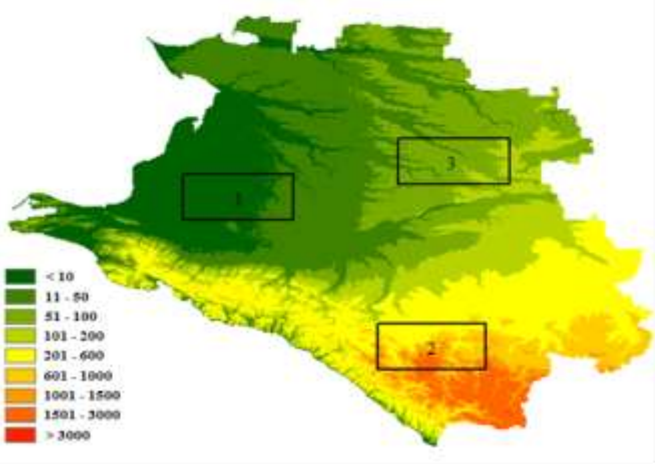

Fig. 1:. The digital model of SRTM for Krasnodar Territory with detailed areas. The area 1 is flat, up to 50 m high; 2 area - mountains, in general more than 600 m above sea level; 3rd - hilly, up to 200 m.

An original resolution of SRTM is 1 pixel = 90 x 90 m. Each of three image sections is degraded by 2 and 4 times, respectively using simple average technique. Thus, the resolutions of test sites have become 180 and 360 m.

3. Basic Principles of Interpolation Methods

In order to restore the data (of interpolation), the following seven image processing and geostatistical methods were used.

3.1 Image Processing Methods

3.1.1 Bilinear Interpolation Method

A bilinear function is the function of two arguments t and u, which, at a fixed value of t, is linear by u and vice versa. A bilinear spline is a two-dimensional generalization of one-dimensional linear spline and has the same advantages and disadvantages. It is composed of bilinear functions defined on each grid cell so that they take prescribed values in the grid nodes. This method of interpolation is good for its simplicity and speed. The main drawback is the discontinuity of the interpolating function derivative at the boundaries of grid cells [9].

3.1.2 Bicubic Interpolation Method

Cubic spline guarantees the continuity of the first and the second derivatives of a function. The bicubic spline guarantees the continuity of only a gradient and a mixed derivative, and the continuity of the second derivatives is not guaranteed. In order to develop a bicubic spline, the values of a function at the grid nodes are required, as well as the values of its gradient and a mixed derivative [9].

3.2 Geostatistical Methods

3.2.1 Simple Kriging Method

A simple (ordinary) kriging suggests the following model [4]:

$$Z(s) = \mu + \varepsilon(s), \qquad (1)$$

where μ is a known constant - a constant average for data without a trend, ε(s) is a random error with a spatial dependence, s(X, Y) are the coordinates of a point, Z(s) is the value of the measured value at a given point.

The interpolator is obtained as a weighted sum of data [4]:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i), \qquad (2)$$

where $Z(s_i)$ – measured at i-th point, λ_i - unknown weight for the measured value $Z(s_i)$, s_0 – the coordinates of the sought point, N – the number of reference points. The weight λ_i depends on the distance to a desired point, and on the spatial relationships between the reference points located around a desired point. The sum of the weights makes one.

3.3 The Method of Inverse Weighted Distances (IDW)

The method of inverse weighted distances (IDW) unambiguously assumes that the objects that are nearby are more similar to each other than the objects remote from each other. In order to interpolate the value for an unmeasured position, IDW uses the measured values around an interpolated location. The measured values, the nearest ones to the interpolated location, exert a larger influence on the predicted value than those far from it at a considerable distance.

The interpolation by the method of inverse weighted distances (IDW) is analogous to ordinary kriging, that is, it is carried out by the formulas (1) - (2). However, in IDW method, the weight λ_i depends solely on the distance to a desired point.

3.4 The Method of Radial Basis Functions

Radial basis functions (RBF) - is a number of rigid methods of interpolation; that is, the surface constructed by the use of these functions will pass through all the reference points. Interpolator is a linear combination of basis functions [5]:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \omega_i \phi(\|s_i - s_0\|) + \omega_{n+1}, \qquad (3)$$

where $\phi(r)$ is the radial basis function, $r = \|s_i - s_0\|$ – is the Euclidean distance between the interpolated point s_0 and each reference point s_i, ω_i – the estimated weight values, ω_{n+1} – the bias parameter.

One of the following options is available for the selection in the module as radial functions:

1. fully regularized spline;
2. Spline function with tension;
3. multiquadric;
4. reverse multiquadric;
5. flat spline.

The Geostatistical Analyst module uses a set of n basic functions, one for each reference point.

- The method of universal kriging

Universal kriging assumes the model [4]

$$Z(s) = \mu(s) + \varepsilon(s), \qquad (4)$$

where μ(s) is a certain deterministic function.

In other words, the universal kriging model is analogous to an ordinary kriging model with the same assumptions, except for one: μ(x(s).β) – depends on x(s) – observation covariance vector and β – the vector of unknown parameters.

3.5 The Method of Empirical Bayesian Kriging

Empirical Bayesian kriging is the method of geostatistical interpolation that automates the most laborious aspects of a correct kriging model development. Other kriging methods in Geostatistical Analyst module require manual parameter changes to achieve accurate results, while the EBK method calculates these parameters automatically by splitting the data into subsets and data modeling.

Empirical Bayesian kriging differs from other kriging methods in ArcGIS Geostatistical Analyst Extension using an intrinsic random function (IRF-0) as a kriging model [6].

Other kriging methods suggest that the process follows a common average (or a given trend) with individual deviations from this mean. Large deviations shift to the mean, so the values never deviate too much. Unlike them, EBK method does not imply a trend toward a general average, so large deviations can equally become less or larger.

4. Results

Figures 2-7 demonstrate the differences between an original and reconstructed model from the degraded one. Thus, the modeling error is determined in the shades of red.

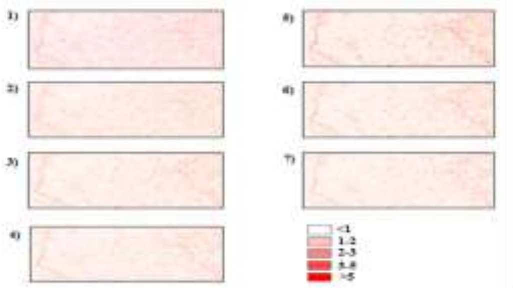

Fig. (2): The difference between an initial raster and an interpolation surface (m) of flat relief area raster degraded by 2 times via the following methods: 1) bilinear interpolation, 2) bicubic interpolation, 3) inverse weighted distances, 4) radial basis functions, 5) simple kriging, 6) universal kriging, 7) empirical Bayesian kriging.

Tables 1-4 show the main statistical indicators of test area simulation error, as well as the initial raster, which help to decide about the preferences of a particular method for raster data restoration.

Table 1:. statistical deviations of the flat relief degraded image in 2 times

Method	Min	Max	Mean	STD
1) bilinear interpolation	-9	14	-0,12	0,87
2) bicubic interpolation	-8	13	-0,1	-0,84
3) simple (ordinary) kriging	-10,65	15,34	-0,17	0,94
4) inverse weighted distances	-9,44	14,51	-0,16	0,91
5) radial basis functions	-12,99	16,75	-0,16	1,12
6) universal kriging	-11,34	15,97	-0,17	0,99
7) empirical Bayesian kriging	-9,78	15,91	-0,17	0,94

Summary: in order to restore the raster of a flat territory, degraded by 2 times, the best results were showed by the method of 2-bicubic interpolation as in the previous cases.

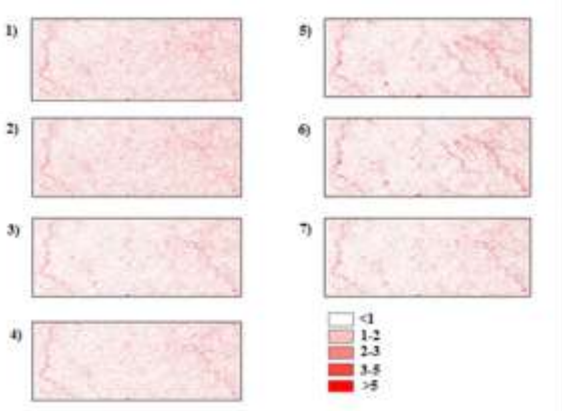

Fig. 3:. The difference between an initial raster and the interpolation surface (m) of relief section raster degraded by 4 times via the following methods: 1) bilinear interpolation; 2) bicubic interpolation; 3) inverse weighted distances; 4) radial basis functions; 5) simple kriging; 6) universal kriging; 7) empirical Bayesian kriging

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Table 2:.statistical deviations of the flat relief image degraded in 4 times

Method	Min	Max	Mean	STD
1) bilinear interpolation	-12	17	-0,1	1,1
2) bicubic interpolation	-11	17	-0,09	1,12
3) simple (ordinary) kriging	-11,94	16,93	-0,17	1,08
4) inverse weighted distances	-10,57	17,04	-0,17	1,11
5) radial basis functions	-14,53	17,13	-0,15	1,23
6) universal kriging	-14,5	17,11	-0,18	1,23
7) empirical Bayesian kriging	-13,8	16,95	-0,17	1,12

Summary: in order to restore a flat territory raster, deteriorated by 4 times, the best results were shown by 2 and 4 methods. Taking into account previous results, the method 2 (bicubic interpolation) dominates.

Table 3:.:statistical deviations of a hilly relief degraded image in 2 times

Method	Min	Max	Mean	STD
1) bilinear interpolation	-13	14	-0,16	1,09
2) bicubic interpolation	-11	13	-0,13	1
3) simple (ordinary) kriging	-11,56	15,06	-0,16	1,46
4) inverse weighted distances	-11	12,33	-0,15	1,3
5) radial basis functions	-20,46	18,19	-0,2	2,37
6) universal kriging	-11	13,2	-0,16	1,32
7) empirical Bayesian kriging	-11,73	13,47	-0,16	1,32

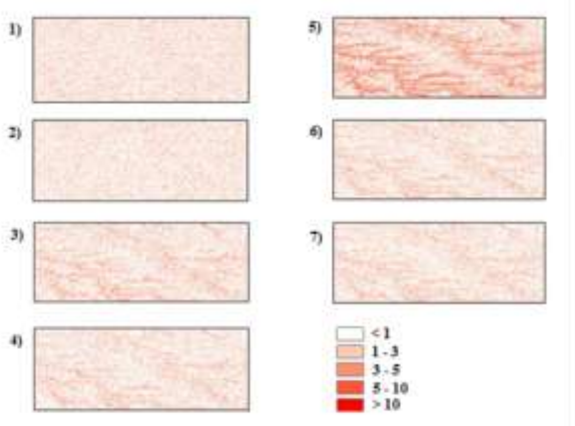

Fig. 4:. The difference between an initial raster and the interpolation of hilly relief region surface raster degraded by 2 times via the following methods: 1) bilinear interpolation, 2) bicubic interpolation, 3) inverse weighted distances, 4) radial basis functions, 5) simple kriging, 6) universal kriging, 7) of empirical Bayesian kriging.

Summary: in order to restore a hilly territory raster, degraded by 2 times, the most suitable method was the method 2 - (bicubic interpolation).

Table 4:. statistical deviations of a hilly relief degraded image in 4 times

Method	Min	Max	Mean	STD
1) bilinear interpolation	-15	18	-0,14	1,63
2) bicubic interpolation	-13	19	-0,12	1,55
3) simple (ordinary) kriging	-17,72	18,15	-0,18	2,01
4) inverse weighted distances	-13,35	18,71	-0,17	1,69
5) radial basis functions	-23,83	18,14	-0,19	3,53
6) universal kriging	-24,23	17,25	-0,2	3,46
7) empirical Bayesian kriging	-16,33	18,48	-0,18	1,7

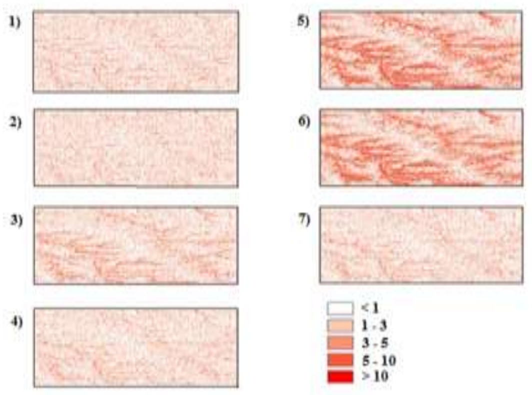

Fig. 5:. The difference between an initial raster and the interpolation of hilly relief region surface raster degraded by 4 times via the following methods: 1) bilinear interpolation, 2) bicubic interpolation, 3) inverse weighted distances, 4) radial basis functions, 5) simple kriging, 6) universal kriging, 7) of empirical Bayesian kriging.

Summary: in order to restore a hilly territory raster, degraded by 4 times, the most suitable methods were the method 1, 2 and 4. Taking into account the previous results, the preference was given to the 2nd method - bicubic interpolation.

Table 5:. Statistical difference for the degraded image of the mountain site in 2 times

Method	Min	Max	Mean	STD
1) bilinear interpolation	-127	103	-0,16	8,97
2) bicubic interpolation	-129	94	-0,13	6,99
3) simple (ordinary) kriging	-163,03	136,7	-1,92	16,39
4) inverse weighted distances	-159,56	128,27	-1,9	13,78
5) radial basis functions	-182,02	221,58	-1,37	28,43
6) universal kriging	-184,79	215,85	-2,9	28,15
7) empirical Bayesian kriging	-154,67	132,13	-1,9	14,06

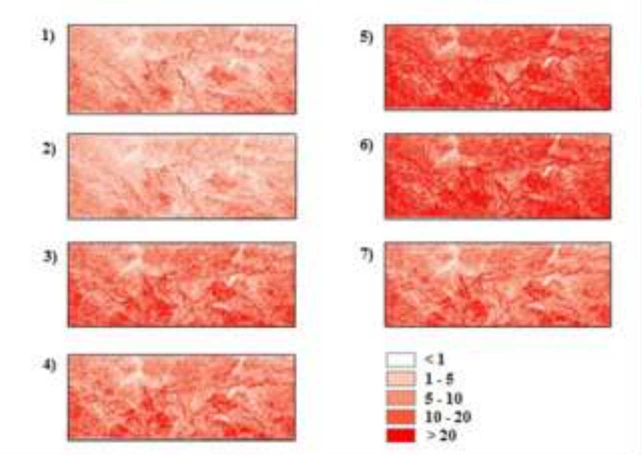

Fig. 6:. The difference between an initial raster and the interpolation of mountain relief region raster degraded by 2 times via the following methods: 1) bilinear interpolation, 2) bicubic interpolation, 3) inverse weighted distances, 4) radial basis functions, 5) simple kriging, 6) universal kriging, 7) of empirical Bayesian kriging.

Summary: in order to restore a mountain territory raster, degraded by 2 times, the most suitable method was the method 2 - bicubic interpolation.

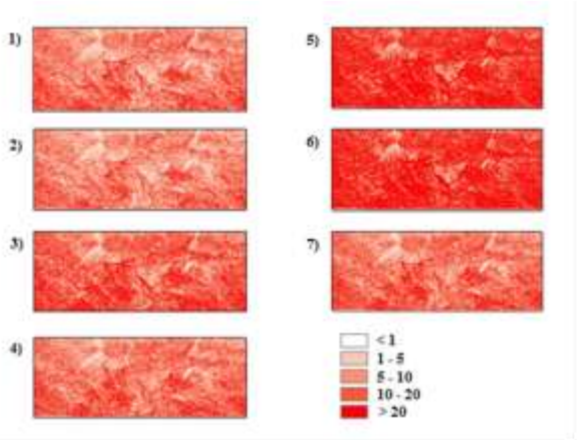

Fig. 7:. The difference between an initial raster and the interpolation of mountain relief region raster degraded by 4 times via the following methods: 1) bilinear interpolation, 2) bicubic interpolation, 3) inverse weighted distances, 4) radial basis functions, 5) simple kriging, 6) universal kriging, 7) of empirical Bayesian kriging.

Table 6:. degraded image of the mountain relief in 4 times

Method	Min	Max	Mean	STD
1) bilinear interpolation	-167	146	-0,12	17,31
2) bicubic interpolation	-178	164	0,14	15,1
3) simple (ordinary) kriging	-191,8	212,05	-2,12	24,99
4) inverse weighted distances	-176,99	154,08	-1,95	18,13
5) radial basis functions	-278,3	293,95	-0,03	47,63
6) universal kriging	-272,19	284,25	-2,98	46,84
7) empirical Bayesian kriging	-171,99	154,89	-0,97	19,04

Summary: in order to restore a mountain territory raster, degraded by 3 times, the most suitable methods were the methods 1 and 2. Taking into account the previous results, the preference was given to the 2nd method - bicubic interpolation.

5. Conclusion

Thus, an undoubted leader was the image processing method of bicubic interpolation, which showed the best results regardless of relief type and raster model compression degree.

Despite the difference in theoretical approaches and formulas, the methods of kriging and radial interpolation lead to the same model function, all other things being equal [7]. This fact is proved in the work of geostatistics founder Matheron [8].

6. Summary

In this paper the different techniques to improve a raster image or model quality were analyzed. The results can be used to restore missing portions of an original raster or model. Including, for example, the monitoring of thermal and other anomalies of the Earth surface or improving of textures for 3D modeling [10-12].

Conflict of Interest

The authors confirm that the presented data do not contain a conflict of interest.

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