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On the detection of gross errors in digital terrain model source data

Tran Quoc Binh*

College of Science, VNU

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Abstract. Nowadays, digital terrain models (DTM) are an important source of spatial data for various applications in many scientific disciplines. Therefore, special attention is given to their main characteristic - accuracy. At it is well known, the source data for DTM creation contributes a large amount of errors, including gross errors, to the final product. At present, the most effective method for detecting gross errors in DTM source data is to make a statistical analysis of surface height variation in the area around an interested location. In this paper, the method has been tested in two DTM projects with various parameters such as interpolation technique, size of neighboring area, thresholds,... Based on the test results, the authors have made conclusions about the reliability and effectiveness of the method for detecting gross errors in DTM source data.

Keywords: Digital terrain model (DTM); DTM source data; Gross error detection; Interpolation.

1. Introduction

Since its origin in the late 1950s, the Digital Terrain Model (DTM) is receiving a steadily increasing attention. DTM products have found wide applications in various disciplines such as mapping, remote sensing, civil engineering, mining engineering, geology, military engineering, land resource management, communication, etc. As DTMs become an industrial product, special attention is given to its quality, mainly to its accuracy.

In DTM production, the errors come from data acquisition process (errors of source data), and modeling process (interpolation and representation errors). As for other errors, the errors in DTM production are classified into three types: random, systematic, and gross (blunder). This paper is focused on detecting single gross errors presented in DTM source data.

Various methods were developed for detecting gross errors in DTM source data [1-5]. If the data are presented in the form of a regular grid, one can compute slopes of the topography at each grid point in eight directions. These slopes are compared to those at neighboring points, and if a significant difference is found, the point is suspected of having a gross error.

The more complicated case is when the DTM source data are irregularly distributed. Li [3, 4], Felicisimo [1], and Lopez [5] have developed similar methods, which are explained as follows:

For a specific point P_i, a moving window of a certain size is first defined and centered on

* Tel.: 84-4-8581420
E-mail: tqbinh@pmail.vnn.vn

P_i. Then, a representative value will be computed from all the points located within this window. This value is then regarded as an appropriate estimate for the height value of the point P_i. By comparing the measured value of P_i with the representative value estimated from the neighbors, a difference V_i in height can be obtained:

$$V_i = \left| H_i^{meas} - H_i^{est} \right|, \quad (1)$$

where H_i^{meas}, H_i^{est} are respectively measured and estimated height values of point P_i. If the difference V_i is larger than a computed threshold value $V_{threshold}$, then the point is suspected of having a gross error.

It is clear that some parameters will significantly affect the reliability and effectiveness of the error detection process. Those parameters are:

- The size of the moving window, i.e. the number and location of neighbor points.

- The interpolation technique used for estimating height of the considered points. Li [4] proposed to use average height of neighboring points for computational simplification:

$$H_i^{est} = \frac{1}{m_i} \sum_{j=1}^{m_i} H_j, \quad (2)$$

where m_i is the number of points neighboring P_i, i.e. inside the moving window.

- The selection of threshold value $V_{threshold}$. Li [4] proposed to compute as:

$$V_{threshold} = 3 \times \sigma^V, \quad (3)$$

where σ^V is standard deviation of V_i in the whole study area. In our opinion, the thus computed $V_{threshold}$ has two drawbacks: firstly, it is a global parameter, which is hardly suitable for the small area around point P_i; and secondly, it does not directly reflect the character of topography. Note that the anomaly of V_i may be caused by either gross error of source data or variation of topography.

In next sections, we will use the above-mentioned concept to test some DTM projects in order to assess the influence of each parameter on the reliability and effectiveness of the gross error detection process. For the sake of simplification, only point source data will be considered. If breaklines are presented in the source data, they can be easily converted to points.

2. Test methodology

2.1. Test data

This research uses two sets of data: one is the DEM project in the area of old village of Duong Lam (Son Tay Town, Ha Tay Province); the other is the DEM project in Dai Tu District, Thai Nguyen Province. The main characteristics of the test projects are presented in Table 1.

For each project, we randomly select about 1% of total number of data points and assign them intentional gross errors with magnitude of 2-20 times larger than the original root mean square error (RMSE). The selected data points as well as the assigned errors are recorded in order to compare with the results of error detection process.

2.2. Test procedure

The workflow of the test is presented in Fig. 1. For the test, we have developed a simple software called DBD (DTM Blunder Detection), which has the following functionalities (Fig. 2):

- Load and export data points in the text file format.

- Generate gross errors of a specific magnitude and assign them to randomly selected points.

- Create a moving window of a specific size and geometry (square or circle) and interpolate height for a given point.

- Compute statistics for the whole area or inside the moving window.

Table 1. Characteristics of the test projects.

Characteristics	Duong Lam project	Dai Tu project
Location	Son Tay Town, Ha Tay Province	South-west of Dai Tu District, Thai Nguyen Province
Type of Topography	Midland, hills, paddy fields, mounds.	Mountains, rolling plain
Data acquisition method	Total station, very high accuracy. RMSE ~ 0.1m.	Digital photogrammetry, average accuracy. RMSE ~ 1.5m.
Project area	~ 90 ha	~ 1850ha
Height of surface / Std. deviation	5-48m / 3.8m	15-440m / 93m
Number of data points	7556	15800
Spatial distribution of data points	Highly irregular	Relatively regular
Average distance between data points	11m	35m
Number of data points with intentional gross error	75	180
Magnitude of intentional gross errors	0.2-2m	5-50m

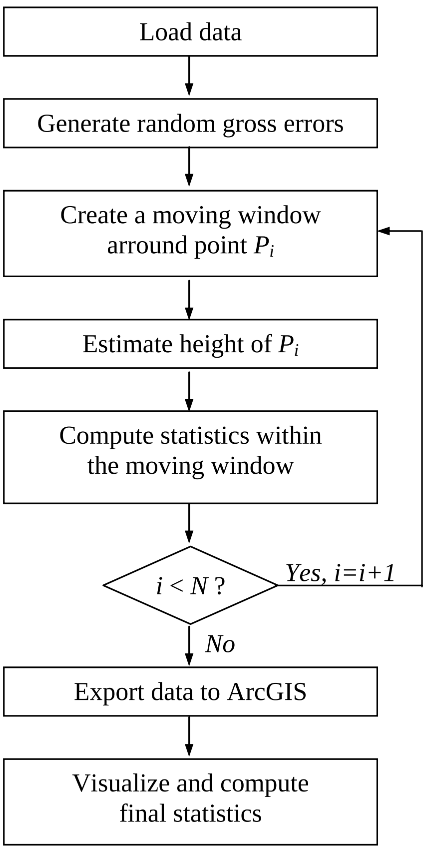

Fig. 1. The test workflow.

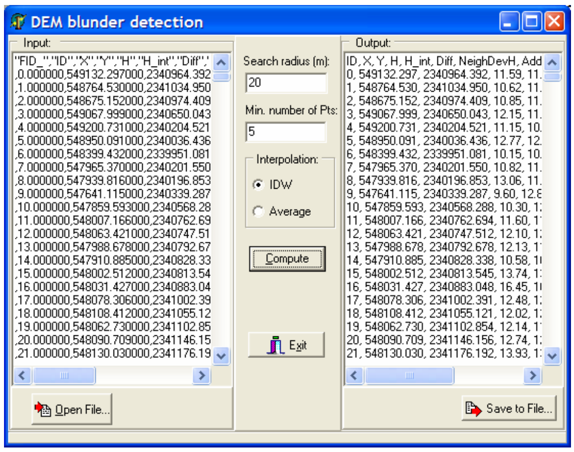

Fig. 2. The DBD software.

The DTM source data points are processed by DBD software and then are exported to ArcGIS software for visualization (Fig. 3) and computation of final statistics.

For estimating height H_i^{est} of a data point, two interpolation methods are used. The first one is simply averaging (AVG) height values of data points located inside the moving window by using Eq. 2. The second one is to use inverse distance weighted interpolation (IDW) technique as follows:

$$H_i^{est} = \frac{\sum_{j=1}^{m_i} w_j H_j}{\sum_{j=1}^{m_i} w_j}, \quad w_j = \frac{1}{d_j^p}, \qquad (4)$$

where m_i is the number of data points that fall inside the moving window around point P_i; w_j is the weight of point P_j; d_j is distance from P_j to P_i; the power p in Eq. 4 takes default value of 2.

For detecting gross errors, two thresholds in combination are used. The first one is based on the variation of surface height inside the moving window:

$$V_{threshold}^H = K^H \times \sigma^H, \qquad (5)$$

where σ^H is the standard deviation of surface height inside the moving window; coefficient K^H takes a value in the range from 2 to 3.

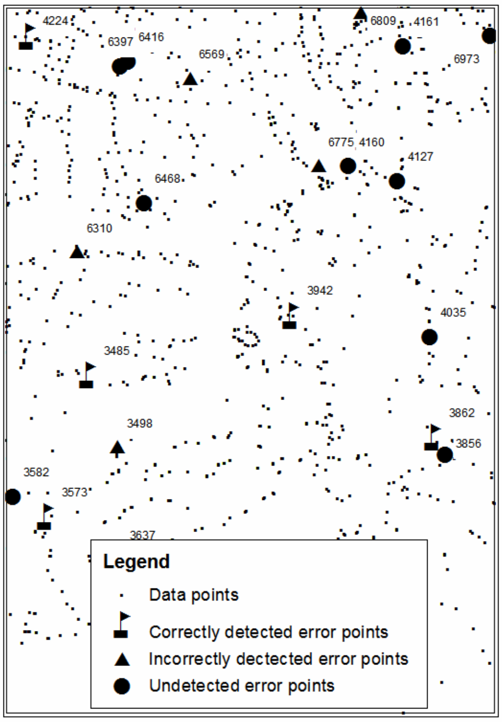

Fig. 3. Visualization of results.

The second threshold is based on the variation of difference V (see Eq. 1):

$$V_{threshold}^V = K^V \times \sigma^V, \qquad (6)$$

where σ^V is the standard deviation of difference value V inside the moving window; coefficient K^V takes a value in the range from 2 to 4.

In some tests, instead of standard deviation σ^V, we used the average value of V inside the moving window and it may give a better result. See section 3 for more details.

3. Results and discussions

For both Duong Lam and Dai Tu projects, we have made several tests with default parameters presented in Table 2. The tests are numbered as DL*x* (Duong Lam) and DT*x* (Dai Tu). In each test, one or two parameters are changed. The computed height difference V_i (Eq. 1) are checked against the two threshold values from Eq. 5 and Eq. 6 with $K^H = 2, 2.5, 3$ and $K^V = 2, 2.5, 3, 4$. The results are shown in Table 2. In DT2, DT7 and DL8 tests, the interpolated value of V at point P_i is used instead of its standard deviation for computing threshold $V_{threshold}^V$. Meanwhile, DT3 test uses data that passed DT1 test with $K^H = 2, K^V = 2$, thus, the input data for this test has only 180-97=83 points with intentionally added error.

From the obtained results, some remarks can be made as follows:

- The almost coincided results of DL1 and DL2 tests show that the intentional errors are well distributed in DTM source data.

- The tested method is not ideal since it cannot detect all of the points with gross error. This is anticipated since the method is based on statistical analysis; meanwhile, the surface morphology usually does not follow statistical distributions. However, the method can be used for significantly reducing the work on correcting gross errors of DTM source data.

- After automated detection, a manual check of marked points is still required for determining correctly and incorrectly detected gross errors.

- The maximum number of gross errors, which can be correctly detected, is estimated as 50-80% of the total number of gross errors existed in the DTM source data: in Duong Lam project, maximum 40 of 75 points with gross errors are detected, in Dai Tu project, these numbers are 145 and 180 respectively.

- The sensitivity, i.e. the smallest absolute value $E_{\min}$ of gross error that can be detected, does not depend on RMSE (root mean square error) of the source data, but it depends on the variation (namely standard deviation σ_H) of surface height in the local area around a tested point. This dependency can be roughly estimated as:

$$E_{\min} \approx 10\% \times \sigma^H \qquad (7)$$

For example, in Duong Lam project with $\sigma_H = 3.5 \div 4.5$m (average: 3.8m), the lowest detectable gross error equals 0.4m. In Dai Tu project, the values are: $\sigma^H = 50 \div 110$m (average: 93m) and $E_{\min} = 7$m.

Table 2. Results of gross error detection presented in format: total number of detected points - number of correctly detected points - minimum value of correctly detected errors.

Test	Changed parameters	Coefficients K^H and K^V for calculating threshold values (Eqs. 5, 6)						
		2 / 2	2.5 / 2.5	2.5 / 3	2.5 / 4	3 / 3	3 / not used	not used / 3
Duong Lam project, default parameters: search radius: 20m; minimum number of points inside the moving windows: 5; interpolation method: IDW.								
DL1	Default	367-32-0.8	163-25-0.8	149-25-0.8	116-22-0.8	93-19-0.9	104-19-0.9	885-35-0.4
DL2	Default, other set of errors	356-31-0.9	154-24-0.9	138-23-0.9	112-23-0.9	87-17-0.9	103-18-0.9	891-37-0.4
DL3	Search radius: 50m	240-24-0.8	102-17-1.1	98-16-1.1	68-15-1.1	36-11-1.1	40-12-0.9	694-28-0.8
DL4	Min. number of searched points: 10	270-26-0.8	96-17-1.1	89-16-1.1	63-15-1.1	42-11-1.1	47-13-1.1	737-28-0.8
DL5	Min. number of searched points: 3	480-39-0.9	259-29-0.9	230-29-0.9	176-26-0.8	163-23-0.9	203-23-0.9	1071-38-0.4
DL6	Interpolation: AVG	271-33-0.8	138-24-0.9	134-24-0.9	117-24-0.9	83-19-1.1	89-19-1.0	865-40-0.4
DL7	Interpolation: AVG Search radius: 50m	156-23-0.9	69-16-0.9	67-15-1.1	51-15-0.9	30-11-1.1	32-12-1.1	675-29-0.9
DL8	Interpolation: AVG σ^V interpolated AVG	251-33-0.8	125-24-0.9	110-24-0.9	82-22-0.9	72-19-0.9	89-19-1.0	377-36-0.5
Dai Tu project, default parameters: search radius: 100m; minimum number of points inside the moving windows: 5; interpolation method: IDW.								
DT1	Default	272-97-7	125-83-12	123-84-12	99-80-12	81-71-12	83-71-12	1187-141-12
DT2	σ^V interpolated IDW	258-97-7	118-83-12	113-82-12	94-77-12	77-69-12	83-71-12	401-118-12
DT3	Uses output of DT1	205-3-8				16-1-9	18-1-9	1285-47-8
DT4	Min. number of searched points: 10	270-95-8	125-83-12	123-83-12	98-79-12	81-71-12	82-70-12	1183-141-12
DT5	Interpolation: AVG	162-101-8	98-83-12	98-83-12	91-80-12	75-68-12	77-68-12	1168-145-12
DT6	Interpolation: AVG Min. num. of pts: 10	162-100-8	97-82-12	97-82-12	90-79-12	75-68-12	76-68-12	1164-145-12
DT7	Interpolation: AVG σ^V interpolated AVG	159-100-7	97-83-12	95-82-12	84-78-12	74-68-12	77-68-12	259-137-12

- By comparing DL1 test with DL3, DL4, DL5, or DT1 with DT4, one can see that with an increase of the search radius (or of the minimum number of points inside the search window), the number of correctly and incorrectly detected points is decreasing. This can be explained as a large number of points participated in interpolation can give averaging effect on the estimated height of a point. This effect is clearly seen on a highly irregular data set (Duong Lam project), while it is insignificant on a relatively regular data set (Dai Tu project).

- The higher the value of threshold values, the smaller the number of correctly detected gross errors, while the number of incorrectly detected gross errors is decreasing too. Thus, the choice of the optimal threshold values is not obvious and should be based on the requirements of the speed and reliability of the test in a specific situation.

- The threshold $V^V_{threshold}$ gives a much larger number of correctly and incorrectly detected gross errors than $V^H_{threshold}$. Thus, $V^V_{threshold}$ should be used when the reliability of a test is the most important requirement.

- Despite the dispute on effectiveness of the simple interpolation by averaging the height of neighbor points, the practical results in the tests DL1, DL6, DT1, and DT5 show that the AVG interpolation is actually better than the IDW one. Our explanation is that the variation of surface height does not follow statistical distributions, and thus the more statistically sophisticated method does not always give a better result than the simple one.

- When using a condition on $V^V_{threshold}$, it is better to use the average value of V inside the moving window instead of standard deviation σ^V. For example, in the tests DL8 and DT7, which use the average value of V, the number of incorrectly detected errors is 3-5 times less than in the tests DL6 and DT5, while the number of correctly detected errors remains almost the same.

- If the data are undergoing multiple tests then in the second and subsequent tests only condition on $V^V_{threshold}$ makes sense. In the above experiments, DT3 test used the data passed and corrected after DT1 test. It can be readily seen in Table 1 that only the single condition on $V^V_{threshold}$ can detect a good number (47) of gross errors, though the number of incorrectly detected errors is still very large in this test.

4. Conclusions

The gross errors presented in DTM source data can be detected by comparing the measured height of a DTM data point with an estimated height by interpolation from neighboring data points. This method can detect 50-80% total number of gross errors with sensitivity of about 10% of standard deviation of surface height.

Two thresholds can be used as criteria for inferring gross errors: one is based on the variation of surface height; the other is based on the variation of height difference (Eq. 1) of neighboring data points. The choice of the optimal threshold values should be based on the requirements on the speed and reliability of the test in a specific situation.

Since the surface height variation usually does not follow statistical distributions, a more sophisticated statistical technique does not always give a better result in detecting gross error of DTM source data than a simple one.

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