

# INTERPOLATION METHOD CONSISTENCY ANALYSIS IN THE CREATION OF DIGITAL TERRAIN MODELS

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## ABSTRACT:

The present paper proposes to analyse the consistency of several interpolation methods for generating a grid structure, which will be used for digital terrain modelling in the case of water retention basins (polders). The aim is to use a single dataset, from which a number of measured points will be eliminated, after which several interpolation methods will be applied to the remaining dataset in order to analyze which method yields the nearest correct (measured) value. The research focuses on comparing the reliability, consistency and sheer data accuracy (in comparison with pre-determined control points) of both the resulted grids and the noise filtered ones, to assess the performance of each method.

## 1. INTRODUCTION

Digital terrain models can be obtained based on two separate principles: using a grid structure or using a TIN (Triangular Irregular Network) structure (Suba et al., 2018). There are various advantages and disadvantages in using any of the aforementioned approaches (De Wulf et. al., 2012), but the general principle remains the same – using an arbitrary disposed dataset (from a mathematical and statistical perspective) to generate, view and analyse the resulted digital terrain model. These data are frequently obtained from field measurements (GNSS or total station surveying), and while there are also other data sources available (ex. remote sensing) for this purpose (Lalak et. al., 2018; Ravibabu et. al., 2008), they either lack the single point precision for various applications, or result in generating a digital elevation model rather than a digital terrain model, because of the vegetation and/or other obstacles (Stereńczak et. al., 2016).

Digital terrain models (DTMs) have been an important topic in geography and surveying sciences for decades due to their geomorphological importance as the reference surface for gravitation-driven material flow, as well as the wide range of uses and applications (Oksanen, 2006). These applications range from simple data visualization to volumetric calculations such as water retention calculations in polders (Suba et. al., 2018; Suba et. al., 2017).

The present paper will put emphasis on analysing the tendency and consistency of data resulted from applying various interpolation methods to a relatively scarcely determined dataset, used for digital terrain modelling.

## 2. RESEARCH SITE AND METHODS

The research site is located between Botean and Bălaia villages, Bihor County, Romania, and represents a small sized polder (Botean II - as it can be observed in Figure 1).



Figure 1. Botean II polder – research area  
(Image courtesy of: Google StreetView, (C) Google 2021)

GNSS measurements were made in the research area, with a careful approach to avoid high temperatures (Ilies D.C. et. al., 2023), the relative point precision being within  $\pm 0,05$  meters for each of the determined points' coordinates, due to the radio base – rover receiver setup. In order to assess the performance of the different interpolation methods, we have selected a number of 11 (eleven) points from the original dataset, which were eliminated from the dataset for calculating the digital terrain models (grids) using the selected interpolations methods (Figure 2). These points were later used to extract their height value from the resulted grids, and comparing the resulted data to the original data.



Figure 2. Botean II polder – distribution of measured points (Dataset, white colour) and control points (red colour)

The selected control points' coordinates are represented in Table 1. Coordinates X and Y are essential to extract the height data from the exactly same positions from the generated grid, whereas coordinate Z is used to compare the obtained grid height values with the field data height values. Plane coordinates are expressed in Romania's Stereographic 1970 projection (EPSG 3844), while height values are represented in Black Sea 1975 Reference System. All data values in tables and figures are represented in meters.

| Point no. | X          | Y          | Z       |
|-----------|------------|------------|---------|
| 1         | 626823.577 | 284086.217 | 175.249 |
| 2         | 626692.586 | 284148.174 | 179.387 |
| 3         | 626840.513 | 284295.096 | 177.334 |
| 4         | 626715.215 | 284297.099 | 181.471 |
| 5         | 626886.985 | 284436.224 | 181.624 |
| 6         | 626781.618 | 284485.721 | 177.690 |
| 7         | 626728.365 | 284541.258 | 181.324 |
| 8         | 626848.495 | 284693.624 | 178.997 |
| 9         | 626745.879 | 284742.442 | 180.245 |
| 10        | 626872.918 | 284888.875 | 179.927 |
| 11        | 626778.693 | 284956.084 | 180.167 |

Table 1. Selected control points

The interpolation methods used to obtain a grid structure for the dataset were the following:

- Inverse Distance Weighting (in the following notations - IDW)
- Ordinary Kriging (KRIG)
- Minimum Curvature (MINCRV)
- Natural Neighbour (NATN)
- Nearest Neighbour (NEARN)
- Triangulation with Linear Interpolation (TLI)
- Modified Shepard's Method (MSM)

We have used the existing dataset to create the grids based on methods described above. Each grid has been created with a resolution of 5 x 5 meters, yielding a total of 15975 nodes for each grid.

### 3. DATA PROCESSING AND RESULTS

Based on the original dataset, resulted from the field measurements (after eliminating the proposed control points), we have generated a number of seven different grids for the study area. The grid generation algorithms (interpolation methods) were those described in Section 2.

We then proceeded to extract the height values at point coordinates 1 to 11 (as presented in Table 1). The resulting extracted height values are presented in Table 2, where Z\_MEAS represents the height values of the control points as resulted from the field survey, whereas Z\_xxxx refers to the height values extracted from the specific grid (xxxx being substituted with the corresponding abbreviation, as mentioned in Section 2).

| Point no. | Z_MEAS  | Z_IDW   | Z_KRIG  | Z_MINCRV | Z_NATN  | Z_NEARN | Z_TLI   | Z_MSM   |
|-----------|---------|---------|---------|----------|---------|---------|---------|---------|
| 1         | 175.249 | 177.909 | 174.989 | 174.737  | 175.379 | 175.188 | 175.340 | 174.743 |
| 2         | 179.387 | 180.509 | 179.648 | 179.060  | 179.492 | 180.271 | 179.512 | 179.055 |
| 3         | 177.334 | 180.206 | 178.111 | 177.940  | 178.508 | 180.414 | 178.724 | 177.949 |
| 4         | 181.471 | 181.765 | 181.706 | 181.570  | 181.565 | 184.050 | 181.523 | 181.573 |
| 5         | 181.624 | 182.311 | 181.865 | 182.156  | 181.906 | 182.722 | 181.913 | 182.164 |
| 6         | 177.690 | 178.415 | 178.343 | 178.393  | 178.327 | 178.391 | 178.367 | 178.021 |
| 7         | 181.324 | 180.553 | 180.758 | 180.681  | 180.932 | 179.251 | 180.943 | 180.672 |
| 8         | 178.997 | 180.136 | 179.071 | 178.716  | 179.104 | 178.976 | 179.129 | 178.714 |
| 9         | 180.245 | 180.326 | 180.452 | 180.651  | 180.758 | 179.574 | 180.774 | 180.629 |
| 10        | 179.927 | 180.208 | 179.923 | 180.303  | 180.121 | 180.504 | 180.217 | 180.298 |
| 11        | 180.167 | 181.947 | 181.687 | 181.389  | 182.078 | 185.000 | 182.440 | 181.385 |

Table 2. Height values for the control points extracted from the generated grids

In order to give a better overall analysis of the resulted data, the next table will present the point height differences resulted from each grid, rather than the absolute height value. With various other researches assessing either the precision of remote sensing

techniques and / or the precision of digital terrain models generated based on remote sensing data (Ravibabu et. al., 2008; Mesa-Mingorance et. al., 2020; Leonardi et. al., 2012; Maleika, 2015; Balenović et. al., 2018; Szostak et. al., 2021; Blaga et. al.,

2019), we've set a deviation acceptance interval of  $\pm 0,65$  meters for the resulted values for this research (marked with green in the table), with all values above this threshold being considered erroneous (red), although an acceptance threshold up to  $\pm 1,5$  meters still seems usable for a variety of applications (Ravibabu et. al., 2008; Mesa-Mingorance et. al., 2020;

Leonardi et. al., 2012; Balenović et. al., 2018; Szostak et. al., 2021). Table 3 and Figure 3 gives an insight on values and tendencies of the selected interpolation methods (in Figure 3., the horizontal axis with 0 value represents the measured values of the control points, the differences being represented are compared to these theoretically zero error values).

| Point no. | IDW    | KRIG   | MINCRV | NATN   | NEARN  | TLI    | MSM    |
|-----------|--------|--------|--------|--------|--------|--------|--------|
| 1         | 2.660  | -0.260 | -0.512 | 0.130  | -0.061 | 0.091  | -0.506 |
| 2         | 1.122  | 0.261  | -0.327 | 0.105  | 0.884  | 0.125  | -0.332 |
| 3         | 2.872  | 0.777  | 0.606  | 1.174  | 3.080  | 1.390  | 0.615  |
| 4         | 0.294  | 0.235  | 0.099  | 0.094  | 2.579  | 0.052  | 0.102  |
| 5         | 0.687  | 0.241  | 0.532  | 0.282  | 1.098  | 0.289  | 0.540  |
| 6         | 0.725  | 0.653  | 0.703  | 0.637  | 0.701  | 0.677  | 0.331  |
| 7         | -0.771 | -0.566 | -0.643 | -0.392 | -2.073 | -0.381 | -0.652 |
| 8         | 1.139  | 0.074  | -0.281 | 0.107  | -0.021 | 0.132  | -0.283 |
| 9         | 0.081  | 0.207  | 0.406  | 0.513  | -0.671 | 0.529  | 0.384  |
| 10        | 0.281  | -0.004 | 0.376  | 0.194  | 0.577  | 0.290  | 0.371  |
| 11        | 1.780  | 1.520  | 1.222  | 1.911  | 4.833  | 2.273  | 1.218  |

Table 3. Height value differences for the control points

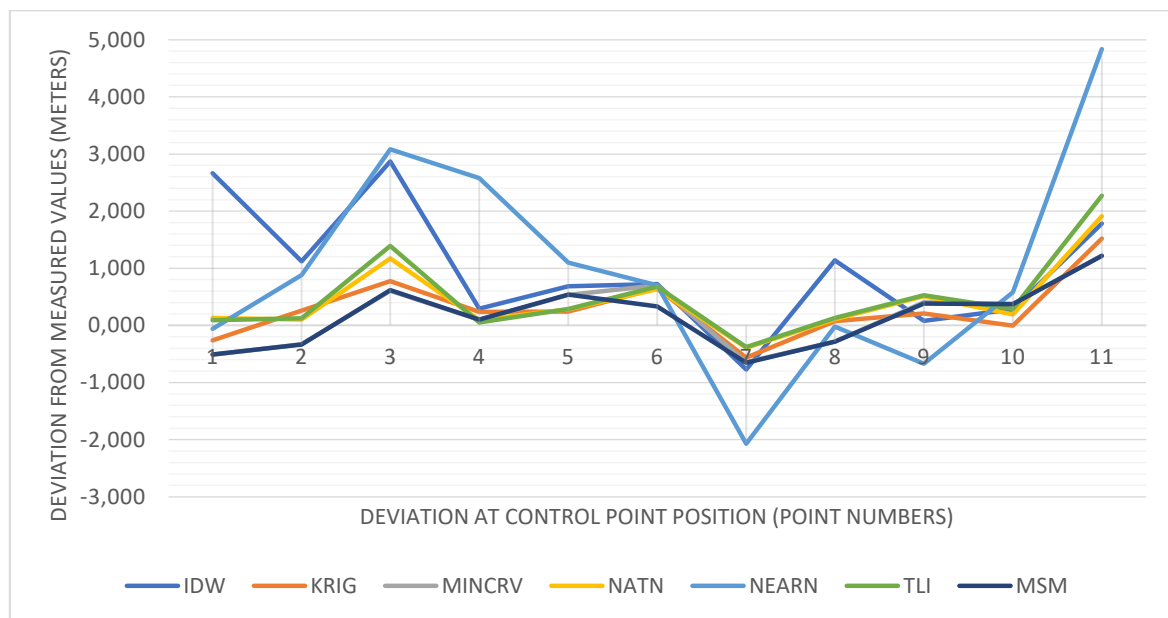


Figure 3. Extracted height value differences compared to the measured values

For point no. 11, none of the methods could provide an adequately accurate value, due to the fringe placement of the control point and the lack of nearby data in all directions, so this control point will be ignored when assessing the reliability of the data. The grids generated with Inverse Distance Weighting and Nearest Neighbour interpolation provided a large scale of erroneous data, with a reliability rate of just 30% (or 40%, if we admit a further 10 percent deviation possibility for the threshold). The other methods provided a reliability rate between 80% and 90%, with Modified Shepard's Method and Minimum Curvature being close to 100% reliability.

In terms of data values, Triangulation with Linear Interpolation and Kriging provided the lowest data deviations from the measured data. On the other hand, in term of consistency regarding the sign of the data values,

Natural Neighbour and Triangulation with Linear Interpolation performed very well, as it can be observed in Figure 3. (in comparison, Modified Shepard's Method provided a good reliability when analysing the values, but has a poor consistency, as the resulting values change their sign from plus to minus quite frequently). These positive or negative differences to the original dataset (and their frequency of change) can determine if the grid calculated with the selected interpolation method follows the natural surface of the research area.

These results are valid for the grids generated without taking into account the shape and data density of the dataset, and as such, no scenario specific parameters have been set when obtaining the grids (for example, search radius for Nearest Neighbour, power value for IDW or Natural Neighbour etc.). Based on the workflow and on the

results, linear convolution filters have been applied to all generated grids. All linear convolution filters compute weighted averages of the neighbouring input grid nodes. The only differences between the various linear convolution filters are the size and shape of the neighbourhood, and the specific weights used (Lyons, 2010). For data filtering, we have used a single low-

pass filter (also known as smoothing or blurring filter), which removes the high frequency noise, with the resulting output being a smoother grid. We then proceeded to extract the height values for the control points, the results being presented in Table 4. and Table 5.

| Point no. | Z_MEAS  | Z_IDW   | Z_KRIG  | Z_MINCRV | Z_NATN  | Z_NEARN | Z_TLI   | Z_MSM   |
|-----------|---------|---------|---------|----------|---------|---------|---------|---------|
| 1         | 175.249 | 177.841 | 175.013 | 174.766  | 175.394 | 175.303 | 175.375 | 174.772 |
| 2         | 179.387 | 180.431 | 179.705 | 179.182  | 179.486 | 180.105 | 179.487 | 179.177 |
| 3         | 177.334 | 180.187 | 178.108 | 177.952  | 178.498 | 180.096 | 178.650 | 177.962 |
| 4         | 181.471 | 181.754 | 181.722 | 181.600  | 181.599 | 182.711 | 181.597 | 181.603 |
| 5         | 181.624 | 182.244 | 181.837 | 182.100  | 181.902 | 182.722 | 181.897 | 182.111 |
| 6         | 177.690 | 178.472 | 178.271 | 178.324  | 178.262 | 178.386 | 178.290 | 177.955 |
| 7         | 181.324 | 180.561 | 180.764 | 180.685  | 180.934 | 179.975 | 180.943 | 180.676 |
| 8         | 178.997 | 180.129 | 179.079 | 178.729  | 179.103 | 179.078 | 179.119 | 178.727 |
| 9         | 180.245 | 180.324 | 180.467 | 180.650  | 180.757 | 180.355 | 180.772 | 180.628 |
| 10        | 179.927 | 180.202 | 179.923 | 180.290  | 180.117 | 180.324 | 180.201 | 180.284 |
| 11        | 180.167 | 181.955 | 181.692 | 181.396  | 182.081 | 184.477 | 182.440 | 181.392 |

Table 4. Height values for the control points extracted from the filtered grids

| Point no. | IDW    | KRIG   | MINCRV | NATN   | NEARN  | TLI    | MSM    |
|-----------|--------|--------|--------|--------|--------|--------|--------|
| 1         | 2.592  | -0.236 | -0.483 | 0.145  | 0.054  | 0.126  | -0.477 |
| 2         | 1.044  | 0.318  | -0.205 | 0.099  | 0.718  | 0.100  | -0.210 |
| 3         | 2.853  | 0.774  | 0.618  | 1.164  | 2.762  | 1.316  | 0.628  |
| 4         | 0.283  | 0.251  | 0.129  | 0.128  | 1.240  | 0.126  | 0.132  |
| 5         | 0.620  | 0.213  | 0.476  | 0.278  | 1.098  | 0.273  | 0.487  |
| 6         | 0.782  | 0.581  | 0.634  | 0.572  | 0.696  | 0.600  | 0.265  |
| 7         | -0.763 | -0.560 | -0.639 | -0.390 | -1.349 | -0.381 | -0.648 |
| 8         | 1.132  | 0.082  | -0.268 | 0.106  | 0.081  | 0.122  | -0.270 |
| 9         | 0.079  | 0.222  | 0.405  | 0.512  | 0.110  | 0.527  | 0.383  |
| 10        | 0.275  | -0.004 | 0.363  | 0.190  | 0.397  | 0.274  | 0.357  |
| 11        | 1.788  | 1.525  | 1.229  | 1.914  | 4.310  | 2.273  | 1.225  |

Table 5. Height value differences for the control points from the filtered grids

Data extracted from the filtered (smoothed) grids reveal that the low-pass filter managed to improve the results. If we eliminate control point number 11 (because of the reasons stated above), only 15 out of 70 data entries have higher values than the ones before, which indicates an improvement rate of over 75% on precision. Also, despite having lower precision at some values, the overall data acceptability rate is also increased, with several additional resulted values now meeting the acceptance threshold. Data consistency slightly changed as well, as there has

been occasion where the difference has shifted from positive to negative or vice versa.

Figure 4 gives an insight on values and tendencies of the selected interpolation methods, similarly to Figure 3, for the filtered grids. As control point no. 11 gave no useful information about the interpolation method efficiency, and due to the fact that Inverse Distance Weighting and Nearest Neighbour interpolation data value reliability still doesn't exceed 40% for the tested dataset, these values have been removed from the graphical analysis.

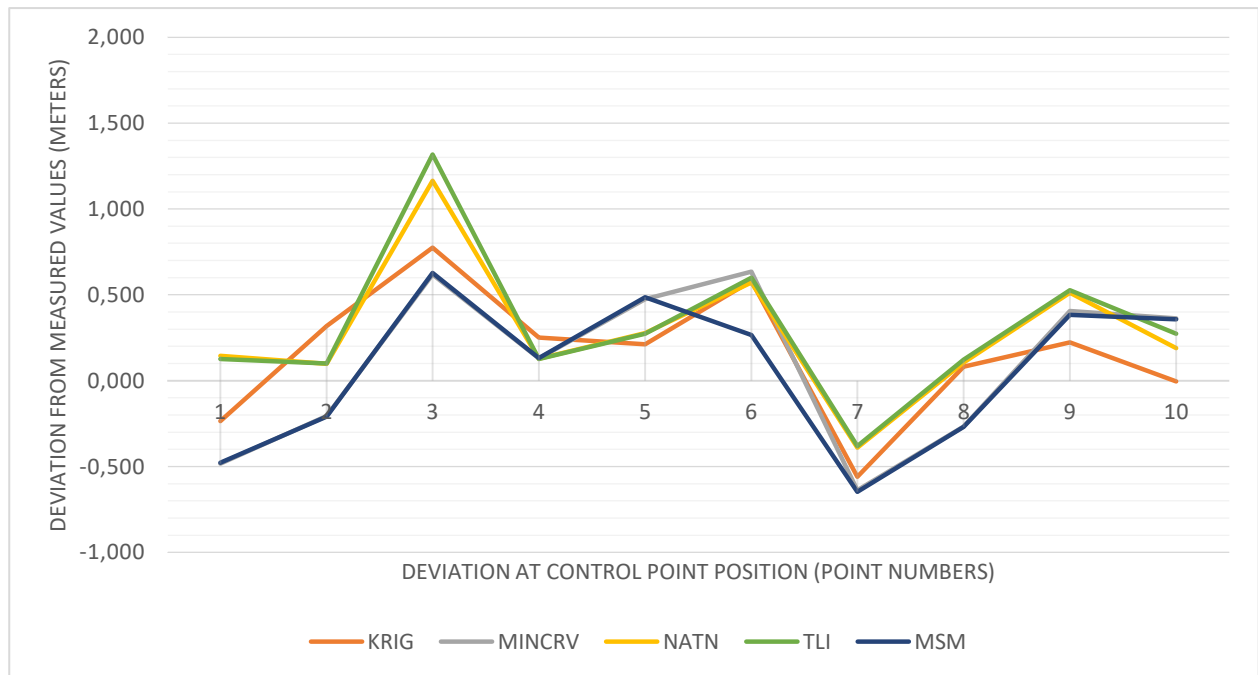


Figure 4. Extracted height value differences compared to the measured values (filtered grids)

#### 4. CONCLUSIONS AND FURTHER RESEARCH

The results of the research gave an insight on the consistency of certain interpolation methods when creating grids for digital terrain modelling. The accuracy and reliability of the Digital Terrain Model is a sensible combination of field data density and accuracy, visual inspection and acceptance, as well as statistical and consistency analysis of data processing (Suba et al., 2018). The results from the applied interpolation methods were analysed in terms of data accuracy (reliability), consistency and sheer data values, compared to the control points' dataset.

Two of the selected interpolation methods (Inverse Distance Weighting and Nearest Neighbour) yielded poor results in terms of data accuracy, when compared to the control points, so for this specific scenario and dataset, the results provided are deemed as not usable. Another notable result is that while Minimum Curvature and Modified Shephard's Method provided a 100% reliability after grid data filtering (the latter result being somewhat of a surprise, given the interpolation method's similarity to Inverse Distance Weighting, which was considered unusable in this scenario), they fall behind the other methods in terms of consistency (highest count of value number sign changes, which indicates that the grid doesn't approximate the natural terrain consistently) and in terms of sheer data values (these two methods provided very similar values when compared to one another, but have the highest mean deviations when compared to the control points).

The remaining three data interpolation methods (Ordinary Kriging, Natural Neighbour and Triangulation with Linear Interpolation) are very close in terms of general applicability in the current scenario. Of course, each of them has certain advantages or weaknesses (for example, Ordinary Kriging has the highest count of result value sign changes, but the lowest mean deviation from the measured data), so we can affirm that these methods can provide reliable grids for digital terrain

modelling for the current scenario and dataset, in terms of reliability, consistency and sheer data accuracy.

Further research on this topic remains open, as there are still several aspects to be studied. First of all, such techniques in digital terrain modelling are frequently used in hydrography-related applications, where natural and seasonal changes can occur (Nistor et. al., 2021) over the lifespan of the studied objective, both at the floodable area and at the constructions. Also, despite the fact that comparison of remote sensing data and field survey data for generating the digital terrain models would be welcome, these data are often obtained with slight differences in the data collection period, and thus being affected by the same seasonality and possible terrain change patterns. Still, further research will focus on comparing both single point accuracy (as these have a major impact on the overall precision of the results (Suba et. al., 2015)) and water retention levels in hydrographic areas (polders), as well as comparing DTM grid results with TIN-based calculations for these objectives.

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