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Research on Modeling Method of Digital Elevation Model for Dense Matching Point Cloud Images in Complex Environments

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Abstract: *In response to the problem of insufficient accuracy in processing dense matching point cloud data of drone images using traditional interpolation algorithms, this study proposes an improved irregular triangulation interpolation algorithm. By filtering the seed points of the triangulation network and adding auxiliary points with maximum boundary values, it is more suitable for dense matching point cloud data. By comparing with traditional Kriging interpolation algorithms, inverse distance weighted interpolation algorithms. The irregular triangulation interpolation algorithm is used to process DEM models generated from dense matching point cloud data, and it is concluded that the improved algorithm proposed in this paper can more accurately reflect terrain features.*

Keywords: *Dense matching point cloud; Kriging interpolation method; Inverse Distance Weighted Method; TIN; DEM*

1. Introduction

The Digital Elevation Model (DEM) is a digital simulation of ground terrain achieved through limited terrain elevation data, that is, the digital expression of terrain surface morphology [1-2]. It is a physical ground model that represents ground elevation in the form of an ordered numerical array. It is a branch of the Digital Terrain Model (DTM), from which various other terrain feature values can be derived. On the basis of DEM, geomorphic characteristics such as slope, aspect, and slope change rate can be derived [3-4].

In recent years, the resolution and accuracy of DEM have been continuously improving. The revolutionary application of high-resolution satellite data, such as the production of 5-meter resolution DEM, utilizes multiple high-resolution satellite data as raw data, builds an intelligent stereo model based on dense matching with point clouds, adopts network distributed and multi-core parallel computing technology, 3D point cloud fusion and terrain extraction technology, and is supplemented by intelligent human-machine interaction editing, achieving a 5m resolution × Production of digital elevation models with a spatial resolution of 5m. This high-resolution DEM data not only improves the accuracy of terrain data, but also provides us with the possibility of better understanding and utilizing terrain information on the Earth's surface.

Compared with radar point clouds, the generation of digital elevation models from drone image data has advantages such as stronger real-time performance, higher resolution, lower cost, richer data, and simpler processing. Using drone image data to generate digital elevation models (DEMs) has become a common task in the field of remote sensing [5].

At present, most research on interpolation methods and evaluation methods is based on Lidar point cloud data, and there is relatively little research on dense matching point cloud data obtained from drone images. This article proposes an improved irregular triangulation interpolation algorithm by comparing the interpolation effects of Kriging interpolation algorithm [6-7], inverse distance weighting algorithm [8-9], and irregular triangulation algorithm [10-12] on dense matching point cloud data, providing data assurance for later point cloud DEM construction and contour lines.

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2. Overview of the experimental area and collection of point cloud data

2.1 Overview of the experimental area

This article selects a certain area of a university as the experimental area, including the middle two teaching buildings, the middle helicopter area, and the surrounding buildings and trees. The overall ground coverage is 127577.4 square meters, which meets the experimental conditions, as shown in Figure 1.

Figure 1: Geographical map of the experimental area

2.2 Point cloud data collection

The image used in this study was a remote sensing image taken by a part of a university campus using unmanned aerial vehicle oblique photography. The resolution was set to 11.6376 millimeters/pixel, heading overlap was 80%, lateral overlap was 70%, and relative altitude was 160 meters. Another simulated ground flight photography was conducted on the measurement area, which included 172 vertical images and 577 oblique images in four directions. A total of 5 flight belts were set up for this flight, with 577 photos, Using the obtained 11.6376mm/pixel oblique image and the calculated POS data, combined with the measurement results of field image control points, aerial triangulation was carried out in the real scene 3D modeling software to obtain dense matching point cloud data. The physical scale of the model was 1:35, and the aerial camera used was the DJI FC6520 unmanned aerial vehicle aerial camera. The point cloud data is shown in Figure 2.

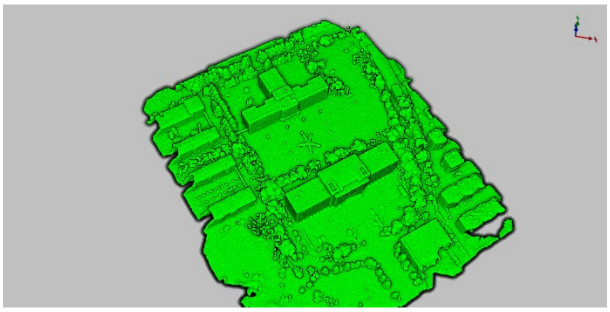

Figure 2: Experimental Area Point Cloud Data

3. Literature References

3.1 Kriging method

Kriging interpolation is a statistical interpolation method, also known as spatial local interpolation. Its principle is to use regionalized variables as the basis and variation functions as the basic tool to perform linear unbiased and optimal estimation on unknown samples. This mainly includes four parts: calculating the sample variation function, modeling the estimated data based on the variation function, using the constructed model for Kriging interpolation estimation, and estimating variance. Kriging's interpolation formula is as follows [13].

$$\hat{z}_0 = \sum_{i=1}^{n} \lambda_i z_i \quad (1)$$

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Where is the estimated value at point (x0, y0), i.e. Here are the weight coefficients. It also uses the weighted sum of data from all known points in an empty room to estimate the value of unknown points. But the weight coefficients are not the reciprocal of the distance, but a set of optimal coefficients that can minimize the difference between the estimated value at point (x0, y0) and the true value, i.e

$$\min_{\lambda_0} Var(\hat{z}_0 - z_0) \tag{2}$$

Simultaneously satisfying the condition of unbiased estimation

$$E(\hat{z}_0 - z_0) = 0 \tag{3}$$

3.2 Kriging method

3.2.1 Basic Principles of Irregular Triangular Networks

The irregular triangulation algorithm is based on point cloud data points to form a series of triangular surfaces to achieve fitting of the earth's surface. When the point cloud density is sparse, it is necessary to set the maximum edge length of the triangulation network to prevent improper fitting of the surface. Triangle networks belong to linear interpolation of point cloud data and can have good fitting effects on structures such as cliffs.2.1.2 Sub heading

The Triangular Irregular Network (TIN) is a method used to represent three-dimensional spatial distribution data, which fits terrain surfaces in the form of an irregular triangular network. The process of generating DEM using TIN can be divided into three steps: data preprocessing, triangulation generation, and elevation interpolation [14].

(1) Data preprocessing

Before generating TIN, elevation data needs to be prepared. Usually, elevation data can be obtained through measurement or remote sensing technology. In the data preprocessing stage, it is necessary to clean, denoise, and fill in missing values on the original data to ensure its integrity and accuracy.

(2) Triangle network generation

Triangle network generation is the core step of generating DEM from TIN. Its goal is to connect elevation data points into triangles, forming a continuous TIN model. The commonly used methods include Delaunay triangulation, insertion algorithm, and incremental algorithm. Delaunay triangulation is an effective algorithm for generating triangulation, whose basic idea is to ensure that the outer circles of all triangles do not contain any other data points. This approach ensures that the generated triangles have good quality and uniformity.

(3) Elevation interpolation

Calculate the elevation of a triangle: Based on the vertex elevation of each triangle, calculate the elevation of each point within the triangle through interpolation. The commonly used interpolation methods include linear interpolation, polynomial interpolation, etc.

3.2.2 Basic Principles of Irregular Triangular Networks

There are certain differences in point cloud density, standard deviation, and other aspects between dense matching point clouds and 3D laser scanning point clouds. Therefore, when directly using traditional irregular triangulation encryption filtering algorithms to generate DEM operations on dense matching point clouds, there are problems such as low accuracy and mismatch, which affect the application of subsequent point cloud data. Therefore, this study improves the traditional algorithm for constructing irregular triangulation by screening candidate seed points and adding boundary auxiliary points.

(1) Seed point filtering. Due to the possibility that the seed points used to construct the triangulation may fall on the object's solid plane, the point may be mistakenly used as the seed point to construct the triangulation, resulting in lower accuracy of the DEM model. Therefore, the accurate ground seed points can be found by screening the seed points into essence. By determining whether each candidate seed point still has a lower elevation than this point within a certain range, if it does, it indicates that this point may not be a ground point and needs to be removed. If there is no point lower than this seed point, it is retained. Finally, the screening of all candidate seed points is completed, as shown in Figure 3.

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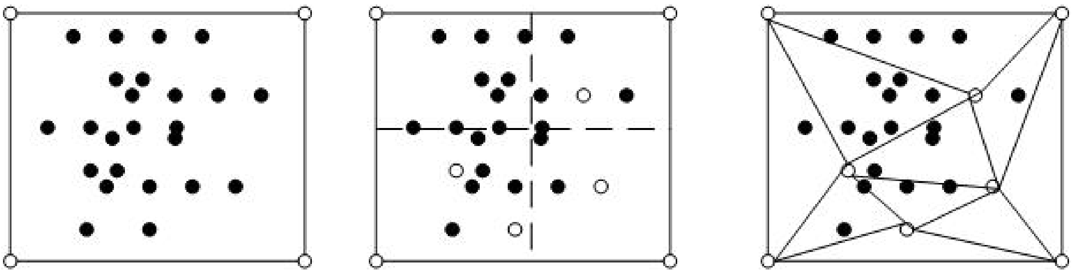


(a) Establish scope *(b) Seed point filtering* *(c) Building a Triangle Network*

Figure 3: Process of constructing an irregular triangular network]

(2) Add boundary value auxiliary points. The boundary value is the upper limit value, and by adding a maximum side length point, the generation of narrow triangles can be effectively controlled. The boundary value is set too small, and the constructed TIN is not continuous enough, showing a sawtooth fracture state; The boundary value is set too large, and the triangular network near the TIN network boundary is too redundant. According to the actual terrain rules, manually adding feature points is used to optimize the boundaries of the 3D network.

3.3 Inverse distance weighted interpolation algorithm

The inverse distance weighting method is a visualization method for river migration research proposed by Jerry Franklin and Patricia Olson from the Washington Department of Ecology. The principle of inverse distance weighting (IDW) method: Using objects that are closer to each other than objects that are farther apart, this method assigns a larger weight to the point closest to the predicted position, while the weight decreases as a function of distance. The IDW tool assigns an elevation radius to the de trend DEM based on the weighted average distance of elevation points within the specified search range. The weighting scheme can effectively give higher weights to elevations that are closer in distance in the average calculation [15-16].

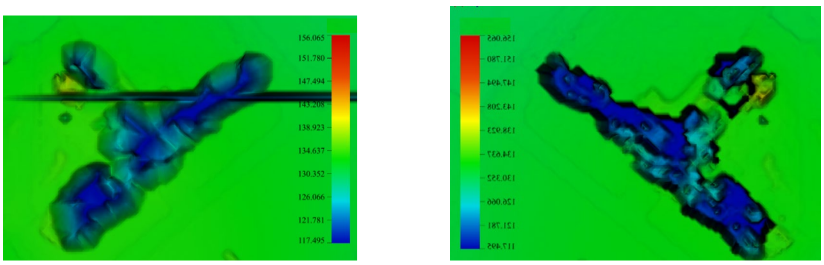
Define the inverse distance interpolation formula estimator for the attribute z=z (x, y) of any point (x, y) in space

$$\hat{z} = \sum_{i=1}^{n} \frac{1}{d^{\alpha}} z_i \tag{4}$$

α is usually taken as 1 or 2. Estimate the value of an unknown point by weighting the sum of data from all known points in space, with weights determined by the reciprocal of the distance (or the square of the reciprocal). So, the closer the point is, the greater the weight; The farther away the point is, the smaller the weight. However, the value of α is usually uncertain, and using the reciprocal to describe the degree of spatial correlation is not accurate enough.

4. Analysis and comparison of experimental results

In order to ensure the comparability of the results of various interpolation methods, the output cell size (set to 3), distance index (set to 5), sampling points (set to 10) and other parameters were set to the same value. Finally, a comparative analysis was conducted from the aspects of time, accuracy, and smoothing ability to obtain the DEM model using different interpolation methods, as shown in Figure 4.



(d1) Kriging interpolation rendering *(d2) IDW interpolation rendering*

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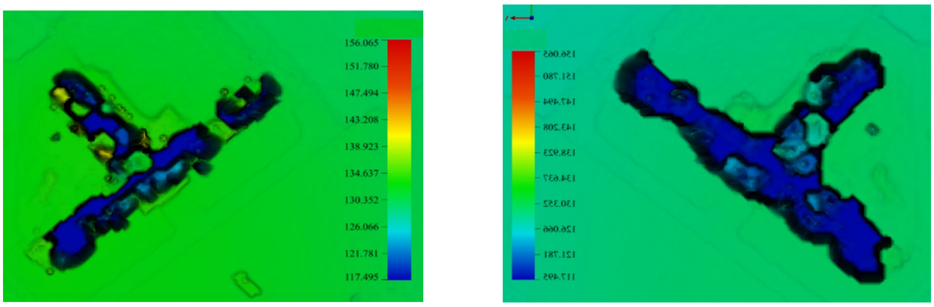

(d3) TIN interpolation rendering *(d4) Improved TIN rendering*

Figure 4: Effect of Different Interpolation Algorithms (Local)

According to Figure 4 (d1), it can be seen that the Kriging interpolation algorithm requires human experience to determine the mutation function, and the final processing effect is not good. It does not handle the accurate value area well, and has a large computational load, requiring a long calculation time. The final effect is the worst among the three interpolation algorithms. From (d2), it can be seen that the inverse distance interpolation algorithm has poor interpolation performance in the missing value area, resulting in a decrease in overall error in the missing value area. According to (d3), it can be seen that the DEM model obtained by using the irregular triangulation interpolation algorithm can better reflect the real terrain compared to the first two algorithms. However, the processing of blank areas in dense matching point cloud data is poor, and the interpolation effect is average. According to (d4), it can be seen that the improved irregular triangulation interpolation algorithm in this article has a more accurate processing effect on missing areas compared to the original algorithm, and overall can better and more accurately restore the real terrain. Table 1 shows the advantages and disadvantages of different interpolation algorithms in processing dense matching point cloud data under the same conditions.

Table 1: Comparison of Different Interpolations

method	advantage	shortcoming	efficiency
IDW	It can be applied to various point cloud data and is relatively flexible, with good interpolation effects for data with high point cloud density.	The boundary of the obtained DEM model is prone to serrations, and when the data is not uniformly distributed, it does not hinder the reflection of changes in the attribute values of the blank area.	low
Kriging	It can effectively eliminate errors in uneven data distribution.	The algorithm is relatively complex and time-consuming to process, requiring a high level of experience from the processing personnel.	minimum
TIN	It can accurately represent the surface morphology and is applicable to all data structures.	If the original points are far away, triangulation is required, and the processing accuracy of point cloud data generated through dense image matching is poor.	high
Improved TIN	It can accurately represent the surface morphology and is applicable to all data structures. It can effectively process dense matching point cloud data and obtain high model accuracy.	The preparation time in the early stage is long, the processing workload is large, and the accuracy of boundary processing is not very high.	high

According to Table 1, from the perspective of operational efficiency and interpolation results, the improved irregular triangulation interpolation algorithm proposed in this paper has the best processing results for point cloud data generated by dense matching of image data. Can more accurately reflect the true terrain features.

5. Summary

For the dense matching point cloud data obtained by using drones to capture images, this paper interpolates the research area using Kriging interpolation algorithm, inverse distance weighting algorithm, irregular triangulation interpolation algorithm, and the improved irregular triangulation interpolation algorithm proposed in this paper, and compares and analyzes the results. The results indicate that these interpolation algorithms have certain limitations, as they are all based on certain assumptions. The Kriging interpolation method considers the statistics of the surface of the object, while the irregular triangulation interpolation algorithm and inverse distance weighting algorithm consider the geometric relationship of the surface of the object.

Taking the point cloud data of a certain university campus after ground point extraction as an example, it can be seen from the interpolation efficiency and effect that the improved irregular triangulation interpolation algorithm proposed in this paper is more suitable for using ground point cloud data obtained from drone images. It can quickly and well restore real ground elevation information, providing data guarantee for later 3D modeling, contour lines, etc.

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