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Digital Modeling of Slope Micro-geomorphology Based on Artec Eva 3D Scanning Technology

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Abstract. In this paper, the three-dimensional (3D) cloud data acquisition of the slope micro-geomorphology is carried out by Artec Eva 3D scanning technology, and the 3D model reconstruction is carried out to realize the digitization of the slope micro-geomorphology. The research results show that the resolution of the digital model is 1.13-1.17 points/mm^2, the standard deviation of the slope modeling is less than 1.2mm, and the maximum error is less than 2mm. The average error is less than 0.1 mm. It can be seen that the digital geomorphology model based on Artec Eva 3D scanning technology can restore the slope micro-geomorphology well, and can apply the 3D digital model to the quantitative analysis of soil erosion process, which can be used in the field of soil erosion monitoring. This technology is of great significance for the study of soil erosion.

1. Introduction

Slope micro-geomorphology is an important influencing factor in the process of slope soil erosion. It has far-reaching significance and effect on the convergence, infiltration, soil structure, run-off and sediment transport process in slope erosion. Its evolution is closely related to the water erosion process [1]. Studying the evolution characteristics and digitization process of slope micro-geomorphology is of great significance for the research of soil erosion process, soil erosion prevention and environmental protection in China [2]. The digital modeling of slope micro-geomorphology is to use a certain mathematical framework to abstract the intrinsic and essential features of geomorphic elements and phenomena in the form of data of 3D models, to reflect and express geomorphological features, spatial distribution and linkages and their development. It provides an objective and accurate basis for geomorphological analysis and decision-making [3].

The 3D micro-geomorphology modeling is mainly composed of data acquisition, data processing and application. The data acquisition method will affect the final quality of micro-geomorphic digital modeling [4]. Common acquisition methods include: large-scale mapping topographic map [5], high-resolution satellite remote sensing or aerial remote sensing [6], 3D scanning technology [7] and microwave remote sensing measurement [8]. Among them, the large-scale surveying and mapping topographic maps are measured by field measurements in the field, but the data acquisition of this method is too large. The data reliability is not high, and the resolution is low. It is applicable only when the data is acquired for large scale mapping in engineering. The remote sensing technology obtains two remote sensing images with higher overlapping ratio, according to the reference point in two The phase

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difference of the image and the acquisition of the elevation, the method has many measurement limiting factors and high acquisition cost, and is suitable for a large area, and only has a high requirement and a wide range of users; the data acquired by the 3D scanning technology has high resolution, strong flexibility, easy access to small-scale data, and low acquisition cost. Geomorphology measurement of artificial rainfall slope scale has problems such as too small data acquisition, high data accuracy requirements, and relatively complex data acquisition. Therefore, for the purpose of effective and high-precision data acquisition for the micro-geomorphology on the slope scale, the introduction of Artec Eva 3D scanning technology for data acquisition is of great significance for micro-geomorphology modeling.

In this paper, the Artec Eva handheld 3D scanner, produced by Artec Corporation of America, is used to model the slope micro-geomorphology. Based on the introduction of the basic principles of 3D scanning technology, the methods and steps of applying this technology to realize the fine slope micro-geomorphology modeling are discussed in detail, in order to establish a high-precision digital model of slope micro-geomorphology. The technology provides a new research method for monitoring the dynamic process of erosion development and revealing the inherent laws of slope erosion.

2. The basic principle of Artec Eva 3D scanning technology

Artec Eva 3D scanner adopts the principle of spatial structure light technology measurement. Firstly, the structured light is projected onto the surface of the object and the structure light is encoded, then the image is captured for decoding, and the internal and external parameters of the device are pre-calibrated to obtain the 3D coordinate information. And the single acquisition process does not depend on other projection patterns, so the problem of dynamic scanning can be better handled. As shown in Figure 1.

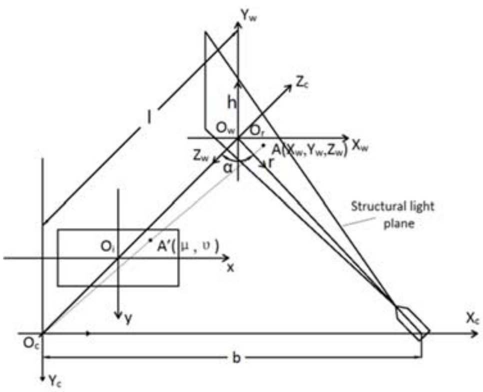

Figure 1. Principle of structured light measurement

The angle between the structured light plane and the camera optical axis is α, and the origin of the world coordinate system Ow-XwYwZw is located at the intersection of the camera optical axis and the structured light plane, and the Xw axis and the Yw axis is parallel to the camera coordinate system Xc and Yc axes respectively, Xw and The Xc direction is the same, Yw and Yc are opposite directions, and Zw coincides with Zc but in the opposite direction. The distance between Ow and Oc is l. Since the rectangular coordinate system Op-uv is defined on the digital image, the coordinates (u, v) of each pixel are the number of columns and the number of rows of the pixel in the image array, (u, v). Is the coordinate of the pixel in pixels in the digital image coordinate system. The physical position of the image point on the image plane establishes an image plane two-dimensional coordinate system Oi-xy expressed in physical units. The coordinate system x-axis and y-axis are parallel to the u-axis and the v-axis, respectively, and the origin is the camera optical axis and image. The intersection of the plane is generally at the center of the image, but there is a small offset in the actual case, and the sitting mark in Op-uv is (u0, v0). The correspondence between pixel points and world coordinate points:

$$\begin{cases} X_w = \frac{f_x(u-u_0)l\cdot\tan\alpha}{f_x(u-u_0)+\tan\alpha} \\ Y_w = \frac{-f_y(v-v_0)l\cdot\tan\alpha}{f_x(u-u_0)+\tan\alpha} \\ Z_w = \frac{f_x(u-u_0)l}{f_x(u-u_0)+\tan\alpha} \end{cases} \quad (1)$$

3. Reconstruction of 3D scan data model

The 3D scanning technology performs high-precision measurement on the whole or part of the object to obtain 3D data such as line surface features and spatial relationships of the object. The discrete points collected from it are called point cloud data.

In this paper, the slope micro-geomorphology is taken as the research object. The Artec Eva 3D scanner is used to obtain the point cloud data of the slope, and then the point cloud data is processed, finally the 3D reconstruction is performed. The main steps are summarized as: data acquisition, point cloud data denoising, fitting registration, construction of 3D models.

3.1. Data acquisition

Firstly, the site survey, the size of the surface, the roughness of the micro-geomorphology, and the detailed features of the slope micro-geomorphology should be investigated, and then a detailed scanning plan is formulated. Ensure that the data finally obtained in each scanning area can represent the complete measurement area and minimize the number of partitions to reduce the amount of original data.

The Artec Eva scanner is a mobile scanner. The dynamic scanning mode of the scanner helps to scan the rills on the surface of the soil. It can adjust the scanning angle in real time for areas that are difficult to scan inside the rill. When scanning the slope, using Artec Studio software monitors the scanned area and the point cloud density of the scan in real time, thereby improving the scanning speed and shortening the field work time while ensuring the quality of the scanning point cloud.

3.2. Point cloud data denoising

There are many rough points in the initial data obtained by the scanner, also known as noise. These noises have a negative impact on the data processing and the construction of the 3D model, so these invalid points or interference points need to be removed.

For the point cloud denoising method, many scholars have carried out research, such as: Bai Zhihui [9] found that the time required to eliminate the point cloud is a quadratic function of the number of point clouds. If the method of fractional calculation is adopted, the processing time will be greatly saved. An entity-based point cloud removal method is proposed, which can eliminate point cloud data far from the surface of the entity, and the obtained point cloud data has higher quality. Sun Zhenglin [10] studied the filtering method of scattered point cloud data, and improved the general Mean-Shift point cloud filtering algorithm. The feasibility and superiority of these algorithms were proved by Matlab platform experiments. Qi Jie [11], using Geomagic Studio software filter tool for experimental analysis, found that B-spline wavelet filtering method has achieved good filtering effect, which can effectively remove the noise of point cloud data, and effectively maintain the topographic features.

In this study, the semi-automatic filtering method is used to denoise the point cloud. First, the point cloud data is counted to determine the effective point cloud range. Then a threshold is set to eliminate the noise outside the effective range. Finally, the manual operation eliminates the noise that cannot be automatically filtered out.

3.3. Fitting registration

In order to obtain the complete 3D landform data of the slope, it is necessary to divide the area to scan the slope surface. The point cloud data obtained by each scan is in a local coordinate system defined by the current center of gravity, and there is no connection between them. The next step of data processing cannot be directly performed. Therefore, the point cloud data needs to be registered, the same control target between adjacent scan data is used to splicing the point cloud data, so that all point cloud data are unified to the same coordinate. It is called point cloud fitting and splicing, also called point cloud registration.

The 3D scanning data can be divided into two ways [12]: 1.based on the control point or target registration method; 2.the nearest point iterative registration method. The nearest point iterative registration method is also called ICP algorithm. The algorithm first needs to search for the closest point in a set of point clouds in a given set of point clouds, then calculate the distance from the nearest point and convert to the unified coordinate system. Next, after iterative iterations until a set of conversion parameters that match the two sets of point clouds are found.

In this paper, the nearest point iterative registration method is used to convert the adjacent two sets of point cloud data into a unified coordinate system by selecting the initial iteration point cloud and setting the number of iterations and the minimum distance of registration. Since the generated point cloud is composed of multiple sets of data, it will inevitably exist that the point cloud data overlaps, the density is different, and the data is redundant, which brings difficulties to the subsequent model establishment, so it is necessary to fit the point cloud data. Perform resampling to limit the density of the point cloud to simplify and reconstruct point cloud data. If the point cloud after resampling is too dense, too many triangle grids are generated, resulting in a large amount of data, which is not conducive to the 3D modeling; if the point cloud after resampling is too sparse, the generated 3D model surface will be lost. Details, therefore, when re-sampling the point cloud data, select an appropriate distance threshold according to the requirements of modeling accuracy, and reduce the number of point clouds as much as possible on the basis of ensuring the fineness of the model.

3.4. Construction of 3D models

The 3D scanner only acquires discrete point cloud data, but in practical applications, it is required to have a 3D model containing object topological relations and geometric information. There are two ways to reconstruct a model: one is a triangular mesh model [13], and the other is a solid model based on object features [14]. In this paper, a triangular mesh model is constructed for point cloud data, and a discrete point cloud in space is used to construct a surface model of the object by forming a triangular patch.

In this paper, the geophysical system software Arc GIS 10 is used to model the slope micro-geomorphology of the point cloud data, and the triangular grid model is used to generate the digital elevation model (DEM) through the mapping tool in Arc GIS.

4. Model accuracy analysis and evaluation

In order to determine the accuracy of the Artec Eva 3D scanner and the reliability of the model built, accuracy analysis and evaluation of the data is required. In this experiment, artificial rainfall was carried out on the loess slope to simulate the natural slope erosion process, and the total rainfall duration was 30 min. The rainfall experiment uses time-separated rainfall, and scans the slope every 10 minutes to record the slope erosion process, and selects the scan data of the same period of the same area for analysis. Table 1 shows the resolution comparison of point cloud data and DEM data. Figure 2 shows the model of rill development in different periods in the same area. It can be seen from Table 1 that the resolution of the point cloud data obtained by the Artec Eva 3D scanner is between 2.2 and 2.6 points/mm^2, and the resolution of the DEM data generated by the interpolation function is between 1.13 and 1.17 points/mm2. Model reconstruction doubled the resolution.

Table 1. The resolution comparison of point cloud data and DEM data

Scanning period	point cloud data	DEM data
Period 1(0min)	2.25 points/mm^2	1.17 points /mm^2
Period 2(10min)	2.31 points /mm^2	1.13 points /mm^2
period 3(20min)	2.56 points /mm^2	1.13 points /mm^2
period 4(30min)	2.35 points /mm^2	1.17 points /mm^2

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(a)0min (b)10min (c)20min (d)30min

Figure 2. Model of rill development in different periods in the same area

Elevation accuracy is the decisive factor reflecting the quality of DEM. In this study, the elevation value obtained by 3D scanning technology is taken as the true value of the sampling point. The modeled DEM elevation value is used as the experimental value, and 200 sample points are randomly generated by ArcGIS data management tool. For the experimental value, the error analysis is performed with the corresponding true value, and the analysis results are shown in Table 2.

Table 2. Calculation results of DEM elevation error in each time period (unit: mm)

Error indicator	0min	10min	20min	30min
Standard deviation	0.242	0.554	1.155	0.215
Maximum error	0.780	1.730	-3.080	-0.670
average error	0.019	0.088	0.092	-0.006

From the error analysis results, the standard deviation of the slope modeling is less than 1.2mm, the maximum error is less than 2mm, and the average error is less than 0.1mm, which fully meets the requirements in terms of accuracy. The DEM indicators of Period 1 and Period 4 are relatively close, and the indicators of Period 2 and Period 3 are relatively close, and the indicators of Period 2 and Period 3 are significantly larger than the DEM indicators of Period 1 and Period 4. The reason is analyzed: since the first period and the fourth period are respectively before the slope erosion occurs and the slope erosion is completed, the slope surface is relatively flat before the slope erosion; after the slope erosion ends, the slope shape is stable; when calculating DEM, the error is small. Period 2 and period 3 occur in the slope erosion process, and the slope morphology is complex and variable. When constructing the geomorphology model, a large error is generated.

5. Conclusion

The Artec Eva handheld 3D scanner provides a new way of thinking for slope micro-geomorphic modeling with a unique point cloud modeling approach. In the process of modeling with Artec Eva 3D scanning technology, the following conclusions were drawn:

1) Artec Eva 3D scanner is light in weight, simple in operation and good in portability, which is good for field measurement. The scanning speed is fast and the distribution of cloud data is very regular.

2) Through the accuracy analysis and evaluation of the slope micro-geomorphic model data in different time periods, the resolution of the slope landform DEM data reached 1.17 points/mm^2, and the Artec Eva 3D scanner can accurately obtain the complex soil rill shape data; The analysis shows that the standard deviation of the slope modeling is less than 1.2mm, the maximum error is less than 2mm, and the average error is less than 0.1mm, which indicates that Artec Eva 3D scanning technology has high precision in the data acquisition stage, and the reliability of constructing the slope micro-geomorphic model is also very high.

Although Artec Eva 3D scanner has great advantages in the modeling of slope micro-geomorphology, there are still many problems to be further studied. For areas with large erosion depth, narrow width, and occluded parts inside the rill, scanning dead spots will inevitably occur; affected by the algorithm of instrument fitting registration, the scan data of the stitching registration needs partially overlapping data and identified feature points, thus limiting the way and angle of data scanning; with the 3D scanning technology with rapid development, 3D scanning processing technology will become more and more mature, and its theory and application will promote the further development of soil erosion.

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