Application of Handheld 3D Scanner in Quantitative Study of Slope Soil Erosion

Peng Wang, Xin Jin* and Shidong Li

School of Environmental Science and Engineering, Guilin University of Technology, Guilin 541004, China

*Corresponding author e-mail: jinxin1390@163.com

Abstract. Simulated rainfall experiment on loess slope. By using Artec Eva handheld three-dimensional (3D) scanner to carry out high-precision scanning of loess slope runoff plots before and after each rainfall, quantitative analysis of slope soil erosion. The results show that using the handheld 3D scanner to scan the slope before and after rainfall, the calculated error of soil erosion is small. The calculated errors of 7 times were -1.428%, 2.843%, -3.189%, 1.141%, -0.945%, -3.240% and 1.287%, respectively. The calculated errors were within ± 4%. Using this scanner, the distribution of slope erosion can be observed very intuitively, and the slope erosion volume and soil erosion amount can be calculated quickly and accurately.

1. Introduction

The slope is the most basic unit of erosion and it is also a basic part of the basin. The acquisition of information on slope erosion and sediment production is crucial for the development of soil erosion prediction models and the acquisition of relevant parameters.

The commonly used method of slope erosion measurement methods can be divided into traditional manual measurement methods and instrument measurement methods. The traditional manual measurement methods include filling method, the volume method [1-3], and topographic needle plate method [3-4]. The instrumental measurement methods mainly include radionuclide tracer method [4-8] and 3D laser scanning method [9-12]. The emergence of these technologies and methods has played an important role in improving the understanding of soil erosion laws and in addressing the distribution of erosion on slopes. The traditional manual measurement method is easy to grasp in the experimental process and data analysis, but the measurement process is easily affected by human factors and other uncertainties, the analysis results often have large deviations from the actual situation. The radionuclide tracer method has been widely used in radionuclide tracing in recent years, and has achieved a great deal of results in the quantitative study of soil erosion. However, the operation process is complex, the preparation and analysis of tracer soil samples are expensive, the cycle is long, and the defects are not easy to grasp. Therefore, despite the high reliability and accuracy of the method, it is still difficult to obtain universal application. The 3D laser scanning technology is based on the laser application and can quickly acquire the coordinate point cloud data of the scanned area, using supporting software to perform 3D modeling on the scanned data. This technology can accurately monitor the microscopic changes and processes of soil erosion patterns, make up for the deficiencies in the microscopic quantitative research of soil erosion, and get high-precision data. At present, the domestic 3D laser scanning technology is based on the ground-based 3D laser scanner Leica HDS 3000. This scanner is used to scan the slope surface. In this study, the scanner, produced by the United States Artec company uses...
the most advanced structure of the structure of the principle of non-contact photogrammetry, the scanner is equipped with a Projector and two cameras. The projector light shines on the object and the cameras at two different angles capture the image at the same time. Due to the different curvature of the surface of the object, the light will reflect and refract on the object, and then this information will be converted into a 3D image through the scanner software of Artec Studio. In the process of scanner movement, the light will change constantly, and the software will recognize and deal with these changes in time. The scanner has the characteristics of simple operation, high processing speed and high precision. It can be used in other detection systems which need to obtain the complete shape information of the object.

In this paper, through artificial rainfall experiment, using the handheld 3D scanner to scan the runoff plots before and after rainfall. The slope erosion amount is obtained by using Artec Studio and Geomagic Control software. Analyzing the calculation process and calculation accuracy, it provides a basis for the application of the technology to the study of large area soil erosion in the field.

2. Materials and Methods

2.1. Experimental Materials

In this experiment, an artificial stainless steel artificial rainfall device was used to carry out artificial rainfall on the soil trough. The rainfall device was a top-spray type and was equipped with a rotary down spray nozzle. The vertical downward spray with pressure was used to supply the submersible pump with a lift of 10 m. The rainfall height of the simulator was 6 m, making the median diameter of the raindrop and the rainfall kinetic energy similar to the natural rainfall conditions. The width and height of the test soil trough were: 400 cm, 120 cm, and 80 cm. The hydraulic device under the soil trough can change the slope of the soil trough, and the gradient changes from 0° to 30°. At the end of the earthen trough, there was a turbulent catchment to collect surface runoff.

The soil used in this experiment was taken from loess of Chabagou, Yulin, Shanxi Province of China. After the soil samples were air-dried, it screened through 1.2 cm sieve to remove large agglomerates and other impurities and used for soil filling. In order to ensure the water permeability of the soil trough, 10cm fine sand was placed on the bottom of the soil trough and covered with water permeable gauze to keep the permeability of the test soil close to the natural slope. By using the method of stratified backfill soil, according to the tank volume and the required density, with 10cm as a layer, edge filling edge compaction, completed a layer of the surface to shave in order to reduce the differences between the layers. In each experiment, the soil of the surface 10cm was dug and re filled in order to ensure that the soil properties of each experiment were basically the same.

2.2. Experimental Equipment

The 3D scanner used in this experiment is Artec Eva, produced by the United States Artec company. The scanner resolution is 0.5mm, the scan data accuracy of 0.1mm, and scan texture definition of 1.3mp. The range is 0.4-1m, the near scan range H×W is 214 × 148 mm, the long scan range H×W is 536 × 371 mm, the scan angle range H×W is 30 × 21°, the video frame rate is 16 fps, and the data acquisition time is 0.0002 seconds. The maximum data acquisition speed is 2 × 10^6 dots per second. The scanner is widely used in animation, medicine, archaeology and other fields [11-14]. The scanner and schematic diagram used in the test are shown in Figure 1. Among them, structured light has been widely used because of its advantages of simple use, accurate measurement, and non-destructive.
Artec Eva uses a composite 3D non-contact measurement technique that combines structured light technology, phase measurement technology, and computer vision technology. Therefore, it is also called "3D structured light scanner." The structured light 3D measurement method is mainly divided into two parts. The first part is to project the structured light and photograph it to obtain the structured light image. Then the structural light is decoded to obtain the structured light image two-dimensional information. The second part is based on the projector, camera and target. The relative position of the object transforms the two-dimensional information of the structured light image into the 3D information of the target object. Different from the traditional 3D scanner, the scanner can measure one surface at the same time. During the measurement, the grating projection device projects a certain number of coded structured light onto the object to be measured, and the corresponding images are simultaneously acquired by two cameras with a certain angle, and then the image is decoded and phase-calculated, and the matching technique is used to create triangles. The principle of measurement is to calculate the 3D coordinates of the pixels in the common view area of the two cameras.

2.3. Experiment related software
The software used in this experiment is Artec Studio and Geomagic Control.

Artec Studio is a 3D scanning and data processing software for handheld scanners. It can perform 3D editing on scanned data. It has scanning function, texture color, auto alignment function, editing and modification functions, smooth function, and automatic optimization of model positioning overall data. Features, edge smoothing and auto-filling, mesh optimization, measurement capabilities, and more.

Geomagic Control is a reverse engineering software of Geomagic Corporation of the United States. The software transforms 3D scan data and polygon meshes into accurate 3D digital models for reverse engineering, product design, rapid prototyping, and analysis. Using its provided parametric modeling capabilities and the ability to capture accurate geometries, the volume can be calculated.

2.4. Test methods
Four different rainfall intensity rainfall tests were carried out on 15° slope soil trough. The rainfall intensity was 40mm/h, 50mm/h, 60mm/h, and 70mm/h respectively; three different rainfall intensity rainfall tests were carried out on 20° slope soil trough. The rainfall intensity was 40mm/h, 50mm/h, 60mm/h, a total of seven rainfall experiments. In order to reduce the effect of soil surface variability on the test results, 30mm/h rainfall intensity was used for prophase rainfall before each test. The purpose of prophase rainfall was to maintain the same previous soil moisture content on the surface of the slope surface, to wet and consolidate the isolated soil particles through rainfall, and to reduce the spatial variability of underlying surface conditions. The total duration of the test rainfall was about 30 minutes. Each rainfall experiment performs 3D scanning of the slope before and after the rainfall to obtain the change patterns before and after rainfall on the slope. Finally, the soil bulk density after rainfall was measured by using the method of cutting ring. When the onset of runoff occurs on each rainfall slope, a 1000-ml graduated cylinder was used to collect runoff samples at the water collection point, and a sample was taken every 1 min according to the actual
production and sediment production. The corresponding sampling time was recorded with a stopwatch. An electronic balance with an accuracy of 0.01 g was used to weigh and the sample volume was recorded. Sample sediment content measured by drying and weighing method.

The collected sample was allowed to stand for more than 12 hours, and the supernatant was extracted. The remaining sediment was poured into a beaker and the beaker was put in the oven at 105° C to heat more than 8 hours. After cooling, the beaker was taken out and weighed to calculate the soil erosion.

3. Results and Analysis

3.1. Analysis of the scanning process

Scanning data processing in the Artec Siduo software after the scan is completed. First, the overall registration and synthesis of the scanned data is carried out to remove the noise and erase the interference data, and the edge data of the slope and the soil trough are retained. Then the entire slope data is exported as triangular mesh data. The obtained triangular mesh data is imported into the Geomagic Control software. The hole filling command can be used to fill the edge of the soil trough, so that the slope surface and the edge of the soil trough form a closed body. Finally, the closed body is calculated by the analysis-calculation-calculate volume command. In this way, the rainfall front and back slope scan data are processed. The two volume differences are the soil erosion volume of the runoff plot during the rainfall. The trough closed body flow chart shown in Figure 2. Take a slope of 15° and a rain intensity of 70mm/h as an example.

![Pre-rainfall slope and enclosed body](image1)
![After rainfall slope and enclosure body](image2)

**Figure 2.** Soil trough closed body flow chart

3.2. Analysis of scan results

By processing the scanning data acquired by the 3D scanner, the shape of the slope surface before and after the rainfall, the triangular mesh data of the volume change, and the volume of the closing body can be obtained. The erosion volume is equal to the volume of the enclosure before erosion minus the volume of the enclosure after erosion. The calculated amount of erosion is obtained by the erosion volume multiply the dry density after rainfall and the conversion unit. In order to verify the accuracy of the 3D scanner to obtain the erosion volume of the slope, the calculated value is compared with the measured value. The measured value during the rainfall process is taken as the actual measurement value, and then the data obtained by the handheld 3D scanner is taken as the calculated value. By comparing the relationship between the two values, the accuracy and precision of the data measured by the handheld 3D scanner can be obtained. The specific equations are as follows:
V = V_a - V_b \quad (1)

M_c = \rho_d \times V \times 1000 \quad (2)

\delta = \frac{M_c - M_e}{M_e} \times 100\% \quad (3)

Where V is the calculated erosion volume; V_a is the closed volume after rainfall; V_b is the closed volume before rainfall; \rho_d is the lope dry soil density after rainfall; M_c is the calculated erosion amount; M_e is the actual erosion quantity; \delta is the relative error.

Sampling on the slope surface using the ring knife method, and using the formulas (1) - (2) to calculate the dry density of the slope after rainfall, calculate the parameters and summarize them in Table 1.

### Table 1. Calculate the amount of erosion

| Number | Slope(°) | Experimental rainfall intensity(mm/h) | Rainfall duration(min) | Erosion volume(dm³) | Erosion amount(kg) |
|--------|----------|---------------------------------------|------------------------|---------------------|-------------------|
| 1      | 15       | 40                                    | 35                     | 32.243              | 47.958            |
| 2      | 15       | 50                                    | 30                     | 60.822              | 84.494            |
| 3      | 15       | 60                                    | 30                     | 60.45               | 88.644            |
| 4      | 15       | 70                                    | 30                     | 80.031              | 116.581           |
| 5      | 20       | 40                                    | 30                     | 39.655              | 58.991            |
| 6      | 20       | 50                                    | 30                     | 49.566              | 73.729            |
| 7      | 20       | 60                                    | 30                     | 95.887              | 127.683           |

### Table 2. Comparing calculated and actual erosion results

| Number | Slope(°) | Experimental rainfall intensity(mm/h) | Rainfall duration(min) | 3D laser scanner erosion(kg) | Measured amount of erosion(kg) | Relative error (%) |
|--------|----------|---------------------------------------|------------------------|------------------------------|-------------------------------|-------------------|
| 1      | 15       | 40                                    | 35                     | 47.958                       | 48.653                        | -1.428            |
| 2      | 15       | 50                                    | 30                     | 84.494                       | 82.158                        | 2.843             |
| 3      | 15       | 60                                    | 30                     | 91.564                       | 91.564                        | -3.189            |
| 4      | 15       | 70                                    | 30                     | 116.581                      | 115.266                       | 1.141             |
| 5      | 20       | 40                                    | 30                     | 59.991                       | 59.554                        | -0.945            |
| 6      | 20       | 50                                    | 30                     | 73.729                       | 76.232                        | -3.240            |
| 7      | 20       | 60                                    | 30                     | 127.683                      | 126.060                       | 1.287             |

#### 3.2.1. Analysis of Accuracy

To compare with the measured results, the comparison results are shown in Table 2. At 15° slope, the measured soil erosion under the rainfall intensity of 40 mm/h is 48.653 kg, and the soil erosion calculated with the handheld 3D scan data is 47.958 kg; the measured soil erosion under the rainfall intensity of 50 mm/h is 82.158 kg, and the soil erosion calculated with the handheld 3D scan data is 84.494 kg; the measured soil erosion under the rainfall intensity of 60 mm/h is 91.564 kg, and the soil erosion calculated with the handheld 3D scan data is 88.644 kg; the measured soil erosion under the rainfall intensity of 70 mm/h is 115.266 kg, and the soil erosion calculated with the handheld 3D scan data is 116.581 kg. At 20° slope, the measured soil erosion under the rainfall intensity of 40 mm/h is 59.554 kg, and the soil erosion calculated with the handheld 3D scan data is 58.991 kg; the measured soil erosion under the rainfall intensity of 50 mm/h is 76,232 kg, and the soil erosion calculated with the handheld 3D scan data is 73.729 kg; the measured soil erosion under the rainfall intensity of 60 mm/h is 126.060 kg, and the soil erosion calculated with the handheld 3D scan data is 127.683 kg. According to the calculation, the error of the experimental results measured by Artec Eva handheld 3D laser scanner for 7 rains are: -1.428%, 2.843%, -3.189%, 1.141%, -0.945%, -3.240%, and 1.287%, respectively. The calculation errors are within ±4%. Zhang Peng et al. calculated the accuracy of the estimated amount of erosion by the high accuracy GPS measurement as 7.38%,
the accuracy of the calculation of the amount of erosion using the topographic needle plate is -12.78%, and the accuracy of the estimation of the amount of erosion calculated using the Leica HDS 3000 3D laser scanner is 4.5%; Ding Wenfeng et al. calculated the accuracy of the erosion calculation accuracy by using the topographic needle plate as 18%, the accuracy of the erosion calculation accuracy by using the REE tracing technique is 13.3%, and the erosion estimation accuracy calculated using the Leica HDS 3000 3D laser scanner The error is 5%. Xiao Hai and others calculated the erosion amount calculated by the 3D laser scanner within 10%.

This work was supported by the National Natural Science Foundation of China (Grants No. 51369009), the Natural Science Foundation of Guangxi Province, China (Grant No. 2016GXNSFAA380116), Guangxi mining and metallurgy and Environmental Science Experimental Center and the Project of High Level Innovation Team and Outstanding Scholar in Guangxi Colleges and Universities (Grant No.002401013001).

4. Conclusion
(1) Using a handheld 3D scanner to scan the slope before and after rainfall, the calculated error of erosion is small, and the error is within ±4%.
(2) Artec Eva 3D scanner can acquire 3D data at a speed of 16 frames per second, each frame is a 3D figure. These frames are automatically aligned in real time. When scanning, you can see the scanned area and the unscanned area. This real-time feedback makes the scanning process faster and easier. Scanning do not need to label the dots, and do not require electromagnetic tracking and calibration.
(3) Compared with 3D laser scanners, handheld 3D scanners have a better description of the detailed evolution of the process of erosion and the spatial variation of the amount of erosion on slopes, and can show the specific development of each rill. The depth of the sulcus can even clearly observe the small eroded pits generated on the slope surface due to raindrop splashing and sheet erosion on the slope surface. At the same time, the 3D scanning technology is superior to the 3D laser scanner in the efficiency of obtaining slope erosion data and the precision of processing data. Handheld 3D scanners use non-laser light sources and are safe to operate. The handheld 3D scanner is very portable and easy to operate, and it is very suitable for on-the-spot field measurement without erection problems.

Acknowledgments
This work was supported by the National Natural Science Foundation of China (Grants No. 51369009), the Natural Science Foundation of Guangxi Province, China (Grant No. 2016GXNSFAA380116), Guangxi mining and metallurgy and Environmental Science Experimental Center and the Project of High Level Innovation Team and Outstanding Scholar in Guangxi Colleges and Universities (Grant No.002401013001).

References
[1] Fenli Zheng. A Research on Method of Measuring Rill Erosion Amount [J]. Bulletin of Soil and Water Conservation, 1989 (4): 41-45.
[2] Pute Wu, Peihua Zhou, Chunlong Wu, et al. Research on the Spatial Distribution Characteristics of Slope Rill Erosion [J]. Research of Soil and Water Conservation, 1997, 4(2): 47-56.
[3] Wenfeng Ding, Pingcang Zhang, et al. Application of Terrain Stylus Plate in Study of Slope Soil Erosion [J]. Soil and Water Conservation in China, 2006 (1): 49-51.
[4] Wenfeng Ding, Pingcang Zhang, et al. Comparative Study of Several Measuring Methods for Soil Erosion on Slope [J]. Journal of Yangtze River Scientific Research Institute, 2015, 32 (11): 14-18.
[5] Hui Shi, Junliang Tian, et al. Using REE Tracer to Study the Source of Sediment in Small Watershed [J]. Scientia Sinica (Technologica), 1996(5): 474-480.
[6] Yaqi Li, Junliang Tian, et al. Application of Activated Stable Nuclide Tracer Method in Soil Erosion Research [J]. Nuclear Techniques, 1997 (7): 418-422.
[7] Puling Liu, Junliang Tian, et al. Studies of Operating Techniques on REE Tracer Method Applying to Soil Erosion [J]. Research of Soil and Water Conservation, 1997 (2): 10-16.
[8] Zhenquan Tang, Gang Liu, et al. REE Tracing Method and Application in Soil Erosion [J]. Journal of the Chinese Society of Rare Earths, 2011, 29(5): 515-522.
[9] Hai Xiao, Zhenyao Xia, et al. Application of Three-dimensional Laser Scanner on Research of Slope Soil Erosion [J]. Bulletin of Soil and Water Conservation, 2014, 34 (3): 198-200.
[10] Jiao Zhang, Fenli Zheng, et al. Methodology of Dynamic Monitoring Gully Erosion Process Using 3D Laser Scanning Technology [J]. Bulletin of Soil and Water Conservation, 2011, 31 (6): 89-94.

[11] Seminati E, Canepa T D, Young M, et al. Validity and reliability of a novel 3D scanner for assessment of the shape and volume of amputees' residual limb models [J]. Plos One, 2017, 12 (9): e0184498.

[12] Yamamoto S, Miyachi H, Fujii H, et al. Intuitive Facial Imaging Method for Evaluation of Postoperative Swelling: A Combination of 3-Dimensional Computed Tomography and Laser Surface Scanning in Orthognathic Surgery [J]. J Oral Maxillofac Surg, 2016, 74 (12): 2506.e1-2506.e10.

[13] Modabber A, Peters F, Kniha K, et al. Evaluation of the accuracy of a mobile and a stationary system for three-dimensional facial scanning [J]. Journal of cranio-maxillo-facial surgery: official publication of the European Association for Cranio-Maxillo-Facial Surgery, 2016.

[14] Peters F, Möhlhenrich S C, Ayoub N, et al. The use of mobile 3D scanners in maxillofacial surgery. [J]. International Journal of Computerized Dentistry, 2016, 19 (3): 217.