Application Research of Terrain Mapping Based on RIEGL 3D Scanning System

Yunen Wu
Yunnan Land and Resources Vocational College, Yangzonghai District, Kunming, Yunnan Province, China
Email: 1251327225@qq.com

Abstract. Based on the RIEGL 3D scanning system, this paper studies the key technical methods of 3D laser scanning technology in the whole process of data acquisition, data processing and topographic mapping, and forms an effective technical route of 3D laser scanning technology in large scale topographic mapping. The transformation relationship among the coordinate system of the scanner itself, the engineering coordinate system, the global coordinate system and the image machine coordinate system is explained. The point cloud data registration, "non-topographic point" filtering technology, arbitrary point cloud data network construction technology and other technical methods are introduced. Better results can be achieved through multi-station acquisition and the combination of GPS and ground 3D laser scanning system.

Keywords. New terrain mapping technology, 3D laser scanning system, coordinate transformation, point cloud data matching.

1. Introduction
At present, China is striving to construct five guarantee systems of informationized surveying and mapping: first, to build a national unified, high precision and dynamic real-time characteristics of the modern surveying and mapping reference system, second, to construct a basic geographic information resource system with good current situation and abundant varieties, third, a real-time geospatial information acquisition system based on aviation, aerospace, ground and offshore multi-platforms and multi-sensors is established, fourth, to build a geospatial information processing system with integrated and intelligent spatial information network and cluster processing technology, fifth, the construction of geospatial information service system with rich geospatial information products and Shared service platform. 3D scanning technology in the application of surveying and mapping geographic information industry is developed in order to adapt to the requirements. It is currently in application to large-scale stage, and getting the point cloud data quickly is no longer a problem, but in the use of point cloud data express terrain, how to quickly and efficiently process point cloud data, how to express it in proper way and to achieve the required precision have become the most concern [1-4].

2. Analysis of New Terrain Mapping Technology
Generally speaking, the development history of topographic mapping technology can be summarized as Large flat sheet with white paper for mapping, theodolite mapping, total station digital mapping of the whole field, GPS real-time dynamic positioning (RTK) mapping, digital photogrammetry (remote sensing, aerial surveying, unmanned aerial vehicle), 3D laser scanning technology, etc. Flat sheet with
white paper for mapping has become a history. Total station and GPS-RTK mapping are being widely used and are being replaced. Digital photogrammetry and 3D laser scanning technology will gradually become the main means of terrain mapping.

The satellite images obtained from the high-resolution remote sensing satellite platform have the characteristics of large range, strong real-time performance and free from airspace control. In particular, it has unique advantages in public security, emergency space information guarantee for emergencies, difficulties and mapping in no man’s land. The highly overlapping images provided by digital aerial photography can technically generate dense matching point clouds and automatically extract digital ground models, which greatly improves the production efficiency of DEM and DSM, making it an ideal data source for modeling, texture extraction and digital city construction. UAV aerial photography system is characterized by flexibility, mobility, efficiency, speed, accuracy and low cost, which is conducive to the rapid acquisition of high-resolution images in small areas and difficult areas, and the measurement of topographic maps based on the principle of aerial survey mapping. Airborne laser scanning (LiDAR) technology can automatically and continuously obtain data with high observation accuracy and high speed. If it can be processed together with image data, the information of the two can be complementary, and the digital elevation model can be automatically generated for large-scale mapping and ground object classification and identification, this technology would have advantages especially in the aspect of city THREE-DIMENSIONAL modeling. The application effect of ground moving mapping system in traffic geographic information is obvious. This system realizes semi-automation in the detection and identification of road environment, auxiliary ground objects information, road damage detection, mileage identification information, traffic signs, street trees, street lamps and other ground objects. It is widely used in the construction of road information database and road safety management. Ground 3D laser scanning technology is a new surveying and mapping technology. It is characterized by high density, high precision and high efficiency. The target information obtained is comprehensive, complete, continuous and correlated. Meanwhile, the spectral information of the target (such as laser reflection intensity, object color, etc.) is also obtained. It can truly records the overall structure, morphological characteristics and spectral characteristics of the target, and provides richer data content for the identification and analysis of the target object [5-9].

3. RIEGL 3D Laser Scanning System Operation Process [10]
High-precision laser ranging technology combined with RIEGL’s original multi-echo receiving and real-time waveform digital analysis technology greatly improves the instrument’s data acquisition capability. It can detect multiple targets, describe objects in detailed detail, and filter out vegetation and pedestrian and vehicle interference with the scanning process, compared with traditional techniques that can only receive one echo pulse at a time.

In general, the operation process of 3D laser scanning system is mainly divided into data acquisition (scanning), point cloud data processing, modeling, data product generation, data output and other links, including data exchange with other processing software. The workflow of 3D laser scanner is shown in figure 1.

![Figure 1. 3D laser scanner workflow.](image-url)
4. 3D Laser Scanning System Internal Data Processing [10]

4.1. Coordinate Transformation
RISCAN PRO uses various Coordinate systems. It is the most importantly the following Coordinate systems:

(1) Scanner’s Own Coordinate System (SOCS): The original data of Scanner is in the coordinate system. Each RIEGL 3D scan data includes each measure geometry information (rectangular coordinates X, Y, Z coordinates or polar coordinates r, θ, ψ) and other information (at least intensity, the colour information can be chosen). Therefore, the data produced by RIEGL 3D laser imaging scanner is an organized data in SOCS.

(2) Project Coordinate System (PRCS) is a user-defined coordinate system. It could be a scan of the site’s existing coordinate system. For example, it can be a device coordinate system. RISCAN PRO requires that all geometric data in this engineering coordinate system be expressed in single digits (7 digits). For example, if mm is used as the unit for accuracy, the maximum coordinate value should be less than 1 km.

(3) Global Coordinate System (GLCS): the engineering coordinate system is included in the coordinate system. The range of values in the global coordinate system can be very large.

(4) Camera Coordinate System (CMCS) is the coordinate System of a high-resolution camera mounted on the top of the scanner.

Figure 2 shows the relationship between GLCS, PRCS, and SOCS. This is a bird’s eye view of the building. The Y-axis (Ypr) is parallel to the center line of the building. The origin of the PRCS coordinate system is exactly a corner point of the building. The PRCS coordinate system is a right-handed coordinate system, and the GLCS coordinate system is a left-handed system, and the scanning site is represented by Spi. Each scan site has its own SOCS, such as the axes of Sp1 (Xsp1, Ysp1, Zsp1).

![Figure 2. GLCS, PRCS, and SOCS.](image)

The position and direction of a scanning station with the scanner’s own coordinate system (SOCS) are determined by the engineering coordinate system. Its Position and direction are described by 6 parameters (3 position parameters, 3 rotation parameters) or expressed by a transformation matrix. RISCANPRO uses a 4×4 matrix (MSOP), it is called SOP information (SOP for sensor’s orientation and Position).

The translation vector is the position vector of the scanner, and the column vector \((r_1, r_2, r_3)\) T is the representation of the coordinate axis of the scanner’s own coordinate system (SOCS) in the Project Coordinate System (PRCS). A 3D scan point can be represented by \(x, y, \) and \(z\) in the same coordinate system, i.e \(P_{hom}=(x \ y \ z \ 1)^T\).
The matrix consists of 9 rotation parameters ($r_{11} \sim r_{33}$) and translation parameters ($t_1 \sim t_3$). Each scan site stores the scan data in a binary data format with the .3DD extension, and each scan site has its SOP information. To convert the data from SOCS coordinate system to the PRCS coordinate system, the data points are simply multiplied by the SCAN site’s SOP matrix to obtain the PRCS coordinates.

If you want to convert a point $P$ from the scan site coordinates to the Global Coordinate System (GLCS), you should first multiply it by the SCAN site MSOP matrix to get the Project Coordinate System (PRCS), and then multiply it by the MPOP matrix to compute from (PRCS) to (GLCS).

See figure 3 for the diagram of coordinate transformation relationship.

$$M_{\text{SCP}}=\begin{pmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Figure 3. Coordinate transformation relation.

### 4.2. Data Registration

Often there are multiple station scans in a project. Data registration (splicing) of each station is required. For the scan point cloud data, there is no distortion or scaling, and the configuration of point cloud data only involves the rigid transformation of rotation and translation. The registration of point cloud data is generally carried out according to the multi-station adjustment method, which is completed through operation in the software, and the point cloud data obtained after multi-station adjustment registration is shown in figure 4.

Figure 4. Point cloud data after Multi-station Adjustment registration (colored).

### 4.3. Filtering Processing

RIEGL has the function of multiple echoes and adopts the full waveform digitization and real-time processing technology, so that the laser can penetrate more vegetation and obtain ground point data. After setting the parameters, RiScanPro can filter vegetation with one click to facilitate subsequent data processing. Topographic filters can separate topographic points from non-topographic points (such as vegetation, small objects, moving objects, abnormal points, etc.). In the filtering process, the “distance” from the point to the “estimated ground” is an important filtering basis. Based on this “distance”, points are classified as “terrain points” and “non-terrain points”. The value of “distance” should be set according to the condition of the survey area. If the value is too large, the purpose of filtering cannot be achieved. If the value is too small, the real terrain points will be filtered out. You
should avoid high density point clouds near the station when you use this feature. Parameters involved in topographic filtering operation include Base Grid size, Number of levels, Tolerance factor, Percentile, Maximum slope Angle, etc.

4.4. Construct Triangulation Network and Graph
It is a common method to express the scanning object in the form of triangulation network which is composed of point cloud data. On the basis of network construction and high-resolution photo information, an approximate realistic model can be built. RISCANPRO provides two networking functions, one for single-site cloud data and the other for arbitrary point cloud data. Here we discuss arbitrary point cloud data networking.

(1) Network construction of cloud data at any point.

The network construction of arbitrary point cloud data is divided into Plane triangulation and Polar triangulation. In the parameter setting of a plane triangle, the main parameter is the Max-triangle Edge Length. This means that a triangle is deleted if one of its sides is greater than the specified value. Max-Triangle Tilt Angle is the Angle between the normals on the surface of a triangle and the line of sight. This means that a triangle is deleted if its inclination is greater than the specified value. The triangle is deleted If any of the inner angles of a triangle (Min. Triangle Angle) is less than the specified value, so as to avoid the appearance of sharp triangle.

There is a Depth Threshold in addition to the above parameters when setting pole-plane triangle parameters. The radial distance between two points should not be greater than the Depth Factor. Center Point can be customized and become a scanning site for data.

(2) Graphics editing and drawing.

After the triangle network is built, it should be modified and adjusted according to the actual situation to reflect the terrain features more accurately. The related elements are edited with editing tools and finally the topographic map is output. This process is similar to the current digital mapping software operation process. Figures 5, 7 are the original point cloud data, and figures 6, 8 are the corresponding graph data.

Figure 5. Raw point cloud data.

Figure 6. Topographic map data.

Figure 7. Raw point cloud data.

Figure 8. Topographic map data.
5. Conclusion
The ground 3D laser scanning system has obvious advantages for the survey area with single topographic elements, such as the area with scarce vegetation and good visibility conditions. For the survey areas with complex features such as urban residential areas, their advantages lie in urban 3D modeling and landscape data production. Any measurement technology is not all-powerful. The ground 3D laser scanner acquires data by receiving reflection information. It is affected by reflection conditions such as distance, angle of view, station position, visibility conditions, roughness of the reflection surface and other factors. It is also impossible to completely scan the measurement area with no omission and full coverage. Therefore, multi-station data collection is the norm for field data collection. The combination of GPS and ground 3D laser scanning system can produce better results. Its application potential still needs the professional technical personnel to explore unceasingly in the practice.

References
[1] Ning J S and Wang Z T 2013 Comprehensive report on the development of Surveying and mapping Discipline 2012-2013 Science of Surveying and Mapping 39(2) 35-37.
[2] Xie H Q, Gao X W and Shao Y 2013 Experimental study on the ranging accuracy of ground 3D laser scanner Bulletin of Surveying and Mapping 39 25-27.
[3] Ling D M, Fan B X, Zhou Y and Qi W Q 2014 Measurement principle and precision analysis of whole station scanner Bulletin of Surveying and Mapping (8) 131-133.
[4] Mao A Q, Zhu Y H and Hao S B, Guo H Q and Song W K 2014 Study on accuracy measurement method and error correction model of ground 3D laser scanner Bulletin of Surveying and Mapping (2) 72-75.
[5] Yan C 2016 Application of 3D Laser real scene technology in the construction of smart city Bulletin of Surveying and Mapping (4) 142-143.
[6] Shi S W, Li Y F, Wang R Z, Li Z K, Hou S C, Li Y and Jin Z S 2017 A modeling technical scheme based on 3D laser point cloud Bulletin of Surveying and Mapping (3) 83-85.
[7] Wang R Y, LI K W, Chen R and Ye B 2018 Application of 3D laser scanning technology in topographic mapping Bulletin of Surveying and Mapping (12) 159-162.
[8] Yang M, Shi X W and Ge H R 2020 Research on the application of three-dimensional scanning technology based on unmanned aerial vehicle Bulletin of Surveying and Mapping (3) 134-139.
[9] Hu Q Y, Gong W L, Hu Y X, Yao C and Ji J J 2020 Reverse modeling based on 3D laser scanning point cloud Beijing Surveying and Mapping 34(3) 352-355.
[10] RIEGL. RISCAN PRO for RIEGL 3D Laser Scanners, Version 1.7.7.