The Key Technology of Three-Dimensional Laser Scanning and Current Status of Engineering Application

Rundong Xu[a], Wei Wang[b, *]

Department of Artillery Engineering, the Army Engineering University of PLA, Shijiazhuang 050003, China

[a]17692178689@163.com, [b]1135565552@qq.com

*Corresponding author

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Abstract: This paper introduces three laser ranging principles widely used in three-dimensional laser scanning system based on the working principle of three-dimensional laser scanning technology. By comparing the mainstream equipment parameters in the market, we can find the technical gap between domestic and foreign counterparts. This paper focuses on the introduction of the overall working process of three-dimensional laser scanning, including the development of scanning plan, field data acquisition and internal data processing, and the introduction of relevant technical details. Finally, the existing problems of three-dimensional laser scanning technology are summarized and the preliminary countermeasures and Suggestions are given.

1. Introduction

3d laser scanning technology originated in the 1980s and developed on lidar technology. It is another technological revolution in surveying and mapping field after GPS. 3d laser scanning can obtain the surface data of scanned objects rapidly, dynamically, with high precision and high density. Therefore, this technology has been widely used in reverse engineering, surveying and mapping engineering, ancient building protection, 3d urban modeling and other fields in recent years. Traditional three - dimensional data acquisition methods include: GPS high - precision positioning, three - dimensional coordinate measuring machine, total station system. The traditional method of collecting three-dimensional coordinates by a single point is inefficient, difficult to describe the entity in detail, cumbersome and inaccurate. 3d laser scanning technology breaks through the traditional single point measurement method and can quickly extract massive 3d coordinate data of the object surface and realize rapid modeling of the object [1].

2. Working principle of 3d laser scanning system

2.1 Working principle

The core function of 3d laser scanning technology is to realize multi-point measurement of object Space coordinates. At present, laser ranging principles [2] mainly include laser triangulation [3], pulse ranging and interference ranging.

2.1.1 Laser triangulation

A part of the laser is received by a CCD camera through a prism. By structuring the light source and the stereo camera as well as the two light information, the stereo projection relationship is constructed, as shown in Figure 1. In this process, the instrument will record the incident and reflected angles of the laser, and calculate the distance between the object surface and the instrument according to the triangular geometry. The use of triangulation ranging type of scanner scanning range is only a few meters, often used for industrial measurement, high precision.

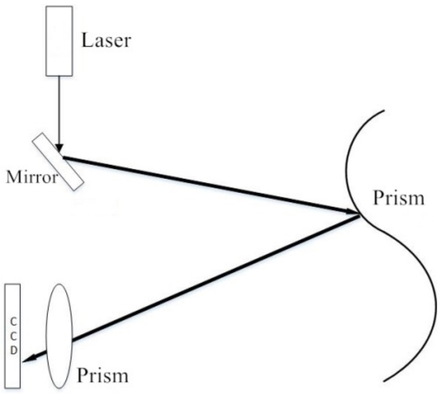

Figure 1. Laser triangulation

2.1.2 Pulse ranging

The main principle of pulse ranging is to calculate the distance between the instrument and the object by measuring the time difference between the transmission and return of the pulse signal, as shown in Figure 2. This kind of equipment consists of laser transmitter, laser receiver, timing module and so on. After receiving the reflected signal, the receiver records the time difference of signal propagation. The signal propagation rate is calculated according to the measured atmospheric refractive index, i.e. $v = c / n$ (n is the atmospheric refractive index), then the distance S can be expressed as:

$$S = \frac{1}{2} v \Delta t \tag{1}$$

As can be seen from equation (1), the ranging accuracy of the pulse method is mainly affected by the atmospheric refractive index and time measurement accuracy. The atmospheric refractive index measurement accuracy is relatively high, which can reach 10-6 orders of magnitude. Therefore, the measurement accuracy of the time interval is the main factor affecting the ranging of the pulse method.

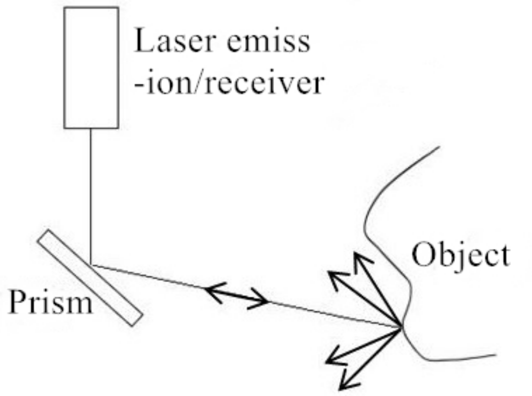

Figure 2. Pulse ranging

2.1.3 Interference ranging

Interferometric ranging uses the continuous wave emission of laser light and determines the measurement method of interference phase according to the interference principle of light. As shown in Figure 3, the laser head emits a laser beam with a single frequency and long-term wavelength stability. When it reaches the spectroscope, it is divided into two beams: a reflective beam ② and a transmitted beam ③. These two beams of light respectively into the cone reflector, and then reflect back into the spectroscope, at this time the two beams of light interference to form an interference light ④, the interference light into the scanner and was detected by the detector.

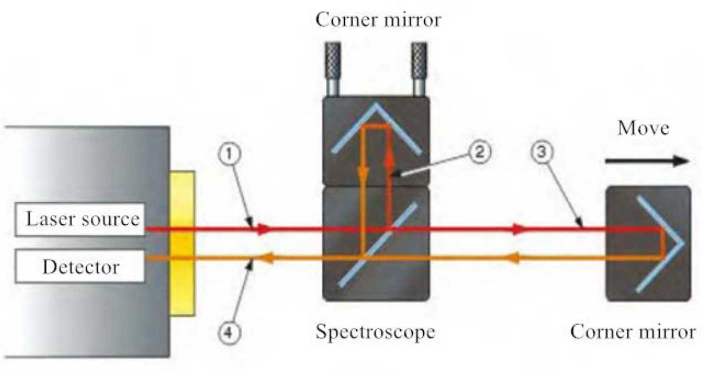

Figure 3. Interference ranging

3. Comparison of major products and parameters in the market

The application of 3d laser scanning technology promotes the development of 3d laser scanning system. Since the advent of laser scanning technology, 3d laser scanning system has been developing rapidly. At present, it has been commercialized and industrialized in some developed countries. Well-known brands include: Leica (Switzerland), Riegl (Austria), Optech (Canada), Topcon (Japan), Trimble (America), etc. Compared with foreign countries, domestic enterprises started relatively late, few enterprises entered this field, and have not formed strong market competitiveness. Table 1 is the parameter details of some current mainstream 3d laser scanning systems [4]:

Table 1. Parameter comparison table of mainstream 3d laser scanning system

Product name	ScanStationP40	VZ-1000	X330	TX8	GLS-2000	Imager 5010
Manufacturer	Leica (Switzerland)	Riegl (Austria)	Faro (America)	Trimble (America)	Topcon (Japan)	Z+F (Germany)
Scanning distance	0.4~270	1.5~1200	0.6~330	0.6~120	350	0.3~187
Scanning range	360°*290°	360°*100°	360°*290°	360°*300°	360°*317°	360°*320°
Scanning accuracy	3mm@50m	5mm@100m	0.3mm@25m	2mm@100m	3.5mm@150m	1mm@50m

As can be seen from Table 1, the scanning distance of the current 3d laser scanning system ranges from the nearest 0.4m to the furthest 350m, covering short, medium and long distances. Scanning scope to realizing a complete coverage of 360° in horizontal and vertical range of the minimum is 100°, the biggest can reach 320°, can contain solid in a single scan range is more extensive; The scanning precision of 3d laser scanning system can control the distance error of 100m to millimeter level.

4. Overall workflow

The whole workflow of 3d laser scanning can be divided into three parts: making scanning plan, field data acquisition and field data processing. Making the scanning plan includes setting the scanning interval and scanning distance, measuring the number of stations and selecting the site location according to the site environment; Field data collection includes target scanning, field analysis of whether the target meets the requirements completely, collection of surface data of scanned objects and control measurement; Internal processing mainly includes data display, data filtering, simplification, segmentation, feature point contour extraction, modeling, etc. The following three tasks are introduced in detail:

4.1 Make scanning plan

The purpose of the scanning plan is to improve work efficiency and reduce unnecessary work. In order to ensure the smooth progress of scanning, field investigation should be carried out in the scanning area in the early stage. By getting familiar with the site, it is possible to grasp the situation of the site, determine the location of the observation point, determine the location of the target, determine the moving route, whether there is power supply, and confirm specific rules.

Figure 4. Field investigation

Among them, the determination of the observation point and the target position should be taken as the key matters: the observation point should be set in the position that can cover all the required surfaces at least; a target is set at the intersection of the view range of multiple observation points. The position of the observation point determines that the concave and convex structure of the measured object and the shaded part formed by obstacles should be imagined [5]. In the setting of scanning interval and scanning distance, both scanning accuracy and scanning efficiency should be considered.

4.2 Field data collection

One of the key steps of 3d laser scanning technology is field data acquisition. The good and bad of field work determines the success and failure of field work. Only when field data are collected well can satisfactory models be produced in the subsequent modeling work. First, the first step is to quickly scan the object under test with a low resolution. The control points are obtained from the point cloud data, and the control points are roughly positioned. The second step is to precisely scan the target. The target is composed of highly reflective materials with regular shapes. The target is scanned with high resolution in the precision scanning technical secondary school. The third step is to fine sweep the area under test. The high-density point cloud data of the target object area can be obtained by setting the appropriate resolution. At the same time, the camera inside the scanner or the external camera carried by the scanner is used to collect the texture photos of the object under test.

4.3 Internal data processing

The original data collected cannot meet the needs of practical engineering applications, so a series of data processing is required, including multi-station splicing, filtering and denoising, point cloud segmentation, feature extraction, 3d modeling and other means. The following is a brief introduction of the above data processing methods.

1) Multi-station splicing: 3d laser scanner can only collect data of a certain part of the object surface from one perspective. In order to obtain the data of the whole surface of the object, it is necessary to measure the object many times from different angles. The common method to splice the main have common point conversion method [6], ICP algorithm [7, 8] and measurement device absolute positioning method [9, 10].

2) Filtering and denoising: during the measurement process, impurities (noise) are easily caused to error due to the scanner's own accuracy, operator's experience, environmental impact and other factors. It is necessary to deal with noise. First filter, and then use specialized algorithm checkpoint cloud data hidden in the noise.

3) Point cloud segmentation: in general, point cloud data with good splicing are difficult to process and difficult to express with mathematical model, so point cloud segmentation is required. The segmentation algorithm can be divided into boundary - based algorithm and surface - based algorithm.

4) Feature extraction: the task of feature extraction is to separate point sets belonging to the same feature surface from the measured data, which is inseparable from point cloud segmentation. At present, two commonly used feature extraction algorithms are feature extraction based on normal vector and feature extraction based on curvature.

5) 3d modeling: the pre-processed data can be used to build 3d models of scanned objects. This mainly includes 3d geometric modeling and texture mapping [11]. Point cloud modeling can not only rely on supporting software provided by hardware, such as RealWorks and PolyWorks, but also use mainstream 3d modeling software on the market, such as 3Dmax and UG. In order to make the model more realistic, the original texture image needs to be processed and then attached to the model surface by software. Thus, a 3d model of the object is obtained.

5. Conclusion

At present, the various operation stages of 3d laser scanning have been relatively mature, but there are still more or less problems in the application of point cloud data acquisition and entity modeling:

1) Domestic research started relatively late, 3d laser scanner is monopolized by foreign manufacturers. To catch up with and surpass the technology, domestic manufacturers need to make joint efforts.

2) At present, the processing methods of point cloud data are not sufficient and complete. Point cloud and model segmentation and classification mainly rely on manual work and cannot be automated, which results in the deviation between the model and the real object to a certain extent.

3) Low interaction between commercial software and single form of database management greatly affect the processing efficiency of point cloud data.

In general, 3d laser scanning technology as the rise of emerging technology in recent years, changed the traditional way of single point of surveying and mapping, to improve the work efficiency and data precision of the measurement, with the deepening of the research, 3d laser scanning technology will be applied in engineering, environmental protection, the archaeological work and a series of field produces an irreplaceable role.

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