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Resolution Model of Terrestrial Laser Scanner

Ling Zhu[1,2] Jianhong Cai[1]

1 Beijing University of Civil Engineering and Architecture, School of Surveying and Mapping Engineering, Beijing, China
2 Key Laboratory for Urban Geomatics of National Administration of Surveying, Mapping and Geoinformation, Beijing, China

Abstract

The aim of the study is the investigation and analysis of the factors affecting the measurements resolution with pulsed time-of-flight (TOF) terrestrial laser scanners. A good understanding of the sources and the relationships between them is necessary to know what size of detail we can get. We subdivide these factors into two groups: internal and external. Based on our studies and the results obtained by other researchers, we have compiled a resolution model for TLS, which is used to estimate the true planer resolution of the point cloud with consideration of the main factors.

Keywords: TLS, resolution, model, accuracy

1. Introduction

Terrestrial laser scanning (TLS) has become an additional technique for data capturing and can be used in many fields such as deformation monitoring, 3D modeling of building or other large scale scene. Though the accuracy requirements for these applications may differ considerably, resolution is an important aspect of any laser scanning survey. As different from traditional survey method, TLS not only involves in the accuracy of single point position but also emphasize the modeling accuracy of the 3D surface. The accuracy of a single point is an important indicator of the data quality, however, since TLS is a surface measurement technique and 3D model is usually the final product, the modeled accuracy could be regarded as the most important relevant indicator of the quality of information obtained. The resolution governs the level of identifiable details within the scanned point clouds and the 3D model could be obtained. Resolution of TLS can be classified into angular, range and intensity resolution. This research mainly focuses the angular resolution which is called as an indicator of resolution. It is the most important one since it determining the spatial scale of the resultant information and deciding on the suitability of TLS for a particular application. The angular resolution or called planer resolution is the size of the smallest feature discernible on a homogenous surface. It is affected by the values of the beam divergence angle and the sampling interval according to the TLS instrument. In addition, the angular resolution of TLS is also a function of geometry setup of the scanner (the scan angle, scan distance) and reflectance characteristic of the object being scanned. These factors can be classified into two major groups: internal and external factors.

2. TLS resolution analysis

2.1 Internal (Instrumental)

The factors related to instrumental portion are all the factors that degrade the point cloud quality according to the laser scanner. The Angular sampling resolution is analyzed using the EIFOV (effective instantaneous field of view) which was proposed by Lichti(Lichti,2006). According to Lichti(Lichti,2006), sampling interval and laser beamwidth affect the spatial resolution of laser scanners. The actual spatial resolution may be much lower than the sampling interval if the beamwidth is larger than the sampling interval because the fine details are effectively blurred. In their paper, they proposed models of both sampling interval and beamwidth, i.e. the EIFOV. The average modulation transfer function (AMTF) was used to model the positional uncertainty due to both factors. The scanning process is modeled as a shift-invariant linear system using the PSF (point spread function) and the measurement is acquired by convolution process. The MTF according to the sampling interval is giving by the modulus of the average PSF's 2D Fourier transform:

$$AMTF_s(u,v) = \left| \frac{\sin(\pi\Delta u)}{\pi\Delta u} \frac{\sin(\pi\Delta v)}{\sin(\pi\Delta v)} \right| \quad (1)$$

Where u and v are the horizontal and vertical angle spatial frequency domain variables. Δ is the sampling interval.

At the other hand, the circular region with diameter δ yields the beam width average PSF, then the corresponding circular beam width AMTF is:

$$AMTF_b(u,v) = \left| \frac{2J_1(\pi\delta\sqrt{u^2+v^2})}{\pi\delta\sqrt{u^2+v^2}} \right| \quad (2)$$

Where J_1 is the 1st order Bessel function of the 1st kind.

Then combine equation (1) and (2) for a square sampling lattice and circular beam, the AMTF is:

$$AMTF_{sb}(u,v) = \left| \frac{\sin(\pi\Delta u)}{\pi\Delta u} \frac{\sin(\pi\Delta v)}{\sin(\pi\Delta v)} \frac{2J_1(\pi\delta\sqrt{u^2+v^2})}{\pi\delta\sqrt{u^2+v^2}} \right| \quad (3)$$

EIFOV is giving by the cut-off frequency, u_c,

$$EIFOV = \frac{1}{2\mu_c} \quad (4)$$

At which ATMF equals a threshold A, $ATMF_{sb}\big|_{\mu=\mu_c} = A$ and A according to this research equals

$$A = \frac{2}{\pi} \approx 0.6366$$

For example, four kinds of TLS angular resolution at 50 meter is listed in the paper of Lichti(Lichti,2006).

Tab.1 angular resolution measured at 50m (Lichti, 2006)

Make	Model	Δ (mm)	δ (mm)	EIFOV (mm)
Leica	HDS2500	0.25	6.0	5.2
Mensi	GS100	1.6	3.0	3.0
Optech	ILRIS-3D	1.3	20.5	17.7
Riegl	LMS-Z420i	2.2	12.5	10.9

2.2 External (object-related, environmental)

2.2.1 Beam width enlarge with scanning range

Not only the instrumental source will give impact on the final product's angular resolution, the resolution is influenced also by factors coming from the scanning setup geometry and the object being scanned itself and the environmental factors. Wavelength of the laser, incidence angle of the laser beam, scanning distance to the object etc are analyzed. Here in this paper, the influence of the external factors will affect the above two main parameters i.e. the beam width and sampling interval. The beam diameter δ increases with the scanning distance get longer, the equation is (Reshetyuk Y,2006):

$$\delta(\mathrm{R}) = \delta_0\left[1+\left(\frac{R\lambda}{\pi\delta_0}\right)^2\right]^{\frac{1}{2}} \quad (5)$$

δ_0 is the beam waist value of the laser beam. For any laser scanning, the δ_0 can be obtained from the vendor's report. If the beam width is provided only at one range, for example, 50meter, the λ always will be provided. Then the δ_0 can be calculated by the equation above. So, the beam width at any range can be obtained according to equation(5). Using equation (3)(4), the EIFOV of any range along the scanning direction can be get.

2.2.2 Sampling interval change with scanning range and scanning angle

Point sampling interval will change with the scanning range and scanning angle. In a scene that being scanned, the sampling interval is different everywhere according to the different scanning range and angle to each point. Here only a specific example is discussed. That is with a plan object being scanned with a distance s .Point clouds obtained from each setup are referenced to the instrument-fixed or internal coordinate system of the scanner. For a "panoramic" scanner, this coordinate system can be described as follows (Reshetyuk Y, 2006):
Origin – in the scanner electro-optical centre;
Z-axis – along the instrument vertical (rotation) axis;
Y-axis – along the instrument optical axis with an arbitrary horizontal angle, e.g. the first horizontal angle or the approximate north on a built-in magnetic compass, if any;
X-axis – orthogonal to the two previous axes, so that the right-hand system is formed.
Each point is defined by spherical coordinates (r, θ, α) or Cartesian Coordinates (x, y, z) in the scanner coordinate system.
Here the scan range s is defined as the closest distance from the scanner to the scanning object surface, also defined as the y axis of the scanning coordinate, then,

$$x = s \cdot tg\theta$$

$$z = \frac{s}{\sin\theta} \cdot tg\alpha \quad (6)$$

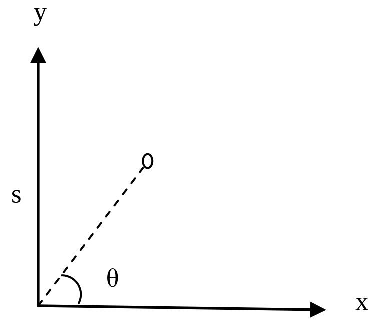

Fig.1 geometry of scanning

here， $90° - \theta$ ， defined as scan angle, is the angle between the scanning direction and Y axis shown in fig.1. It is negative when the point in the left side of Y axis and vice verse. The number of points decreases rapidly with increasing scanning distance. In order to derive the point sampling interval with the change of the scanning range and angle, the equation with partial differential of θ and α is:

$$dx = \frac{sd\theta}{\cos^2\theta} \qquad (7)$$
$$dz = \frac{sd\theta}{\cos\alpha\cos^2\theta}$$

dx,dz considered as the sampling interval and dθ as the horizontal step angle, dα as the vertical step angle. Due to the change of the scanning distance s and scanning angle, the sampling interval will change accordingly regarding with the equation. Giving the value of θ and α in a scanning scene, the sampling interval δ can be calculated with (7). Then using equation(3)(4), the EIFOV of any range and angle can be get.

Figure 2 shows a distribution of points with horizontal distance and incline angle (the horizontal distance is 1~15m, the incline angle is 0 °~60 °.)

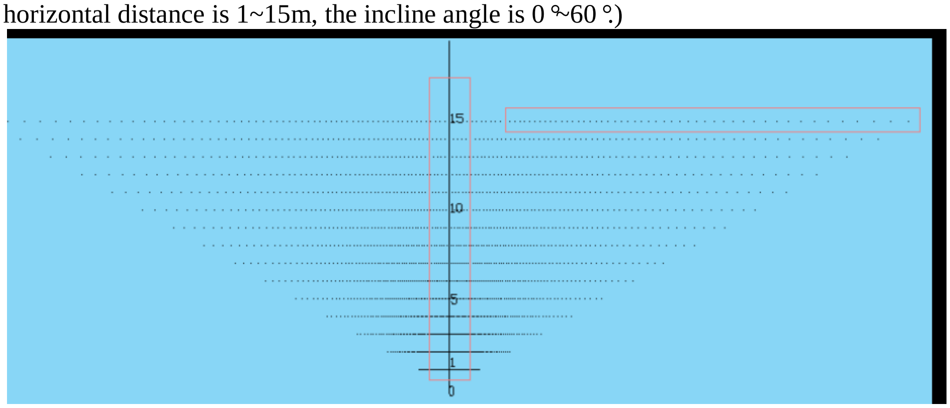

Fig 2. Distribution of Points

In addition, Reflectance of object surface, which is a combination of the following factors including material properties of the object, surface color, surface roughness, each one will give influence to the actual EIFOV, these factors are not discussed here.

3. TLS resolution testament

Three set of TLS of different vendor are used to calculate the resolution according to the resolution model. Field test was carried out to test the effectiveness of the resolution model proposed by this paper.

4. Conclusion

In this paper, the angular resolution of TLS was discussed. The factors influence the resolution was divided into two categories: internal and external factors. The internal factors most caused by the scanner itself. Lichti's (Lichti, 2006) EIFOV was used to quantify the angular resolution. Both beam width and sampling interval were considered in this model. The scanning range and angle change were considered as the external factors herein. The beam width and sampling interval model with respect to the scanning range and angle were given in this paper.

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