Viewpoint planning for terrestrial laser scanning utilising an intensity based stochastic model

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Abstract. Every survey campaign for the sake of engineering geodesy requires thorough viewpoint planning in order to ensure a required precision of the measurements under consideration of economic boundaries. Despite the enormous popularity of terrestrial laser scanners (TLS) in the field of Geodesy both previously mentioned aspects have not been transferred to this established surveying technique. The focus of this contribution is set to determine a viewpoint from which the theoretical precision of all acquired points is optimal. Therefore a novel intensity based stochastic model for a Zoller und Fröhlich Imager 5006 h is experimentally derived. This model considers influences of the acquisition configuration as well as the radiometric properties of the object's surface onto the reflectorless distance measurement.

Keywords. Terrestrial laser scanning, viewpoint planning, stochastic modelling

1 Introduction

A look into geodetic standard literature on the subject of planning and viewpoint configuration reveals parallels between several acquisition methods such as tacheometry (Ghilani 2010 pp. 455) and photogrammetry (Luhmann 2011 pp. 446). Common properties of both techniques include predefined criteria concerning accuracy and reliability yet within acceptable economic boundaries. A direct transition of the described procedures onto TLS is not applicable as both cases assume discrete, repeatedly observable points in object space while only the acquisition configuration is optimised. This case is not given in terrestrial laser scanning as the point sampling on the object's surface is directly dependent to the chosen viewpoint. Consequently observations have to be simulated for all potential viewpoints - this procedure is referred to as ray casting (Appel 1968). In order to conduct ray casting a geometric model of the object of interest has to be known, which is often available prior to a survey e.g. in form of blueprints, previously generated 3D-models at a lower resolution from other sources or any kind of CAD-models. Alternatively scans can be acquired and triangulated in order to receive the required input. In addition a meaningful stochastic model of the deployed laser scanner has to be given that contains information on the precision of angle- and distance measurements. It has to be emphasised that even after more than a decade of intensive research no telling stochastic model has been published for the reflectorless distance measurement unit. If stochastic information about the deployed TLS as well as a geometric model of the object of interest is given, observations can be simulated from a certain viewpoint. Every observation finally receives stochastic properties which describes the fundament for viewpoint planning.
First thoughts on finding optimal TLS viewpoints have been proposed by Soudarissanane et al. (2008) and Soudarissanane & Lindenbergh (2011). As an input a 2D map is derived from a given 3D-model of a scene. While 2D maps may be a suitable simplification for indoor scenarios they are certainly not for complex geometric objects. Böhler et al. (2003) derive the noise of the distance measurement unit from residuals to an adjusted plane which has been scanned before. A similar approach has been proposed by Heister (2006) who chose spherical targets instead of planes. This course of action is subject to several influences that notably falsify the outcome, for instance:

- accuracy of the angular encoders
- spatial resolution of the data as well as the redundancy,
- processing software.

In addition several effects act on the precision of reflectorless distance measurements, such as:

- the object distance (Elkhrachy & Niemeier 2006),
- surface properties (Zámečníková & Neuner 2014),
- varying incidence angles (Soudarissanane et al. 2008).

Soudarissanane et al. (2008) remark in their contribution regarding the incidence angle, that an unfavourable signal-to-noise ratio (SNR) yields to a loss of precision of the distance measurement.

The mentioned relationship between SNR and achievable precision of measurements is also widely known for other survey instruments. Yet, a causal separation of influencing factors onto the SNR cannot be made which lead to the motivation to develop a stochastic model for the distance measurement unit of TLS that considers the acquisition configuration as well as the radiometric properties of an object. Another important factor is that the novel stochastic model should only describe the characteristics of the distance measurement unit of a TLS as this is its key component. As distance measurements are elementary observations, only input parameters should be used to develop the stochastic model that are independent to other elementary observations or derived quantities such as Cartesian coordinates. As a consequence only distance measurements are used to model the stochastic properties of the TLS' distance measurements. Based on the proposed stochastic model and geometric information about the object of interest the search of an optimal viewpoint can be deployed from which the achievable precision in the field is optimal.

2 A stochastic model for a TLS

In order to avoid the mentioned disadvantages a measuring setup is proposed that allows to repeatedly observe a single point. Based on these measurements conclusions can be drawn about the stochastic properties of the reflectorless distance measurement unit of a Z+F Imager 5006 h. A vital optical element in TLS is the photo diode (Mettenleiter et al. 2015 p. 16 ff., Vosselmann & Maas 2010 p. 14) that derives the distance between scanner and object as well as the intensity based on the reflected signal. Mettenleiter et al. (2015 p. 51) state that the noise of a distance measurement is dependent to the energy of the received signal. Thus, the intensity values recorded by the TLS serve as input for the proposed stochastic model as they reflect influences that are caused by the acquisition configuration as well as interdependencies between the signal and object surface.

In order to cover a potentially large spectrum of intensity values eight radiometric samples ranging from black to white have been used. The probes were scanned under varying distances between 5 and 55 m in five metre increments which lead to 80 datasets. Subsequently the average of 1000 observed distances and intensity values has been computed for each dataset. Figure 1 illustrates the relation between recorded intensity and precision of a distance measurement where the measurements are depicted by black dots. It can be seen that the precision of distance measurements decreases in dependence to the signal strength. The run of the plot expresses the characteristics of the applied avalanche-photo-diode (APD) that is a component of the applied TLS (Mettenleiter et al. 2000)

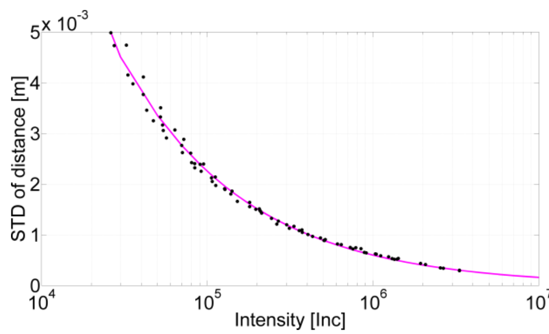

Fig. 1 Intensity vs. precision of a distance measurement

Based on the functional model

$$\sigma_{dist} = a \cdot intensity^b$$

the unknown parameters a and b are estimated within a least squares adjustment where the intensity values *intensity* serve as observations and the standard deviation of distance measurements as fixed values. The estimated values for a = 1.61715 and b = -0.57069 are now capable to express the relationship among signal strength and precision of a distance measurement. Thus, these values describe the stochastic model for reflectorless distance measurements of the deployed TLS. The pink line in figure 1 illustrates the run of the stochastic model. By conducting variance-covariance propagation under usage of the proposed stochastic model for distance measurements and the angular precision of the reflection unit, the spatial precision for all 3D-points can be computed.

3 Viewpoint planning for TLS

As mentioned at the very beginning two essential pieces of information are required for viewpoint planning from the perspective of engineering geodesy namely a geometric model of the object of interest as well as a stochastic model of the applied TLS. While a stochastic has already been proposed in the previous section, a colour coded 3D-model, which has derived by Structure from Motion (Wenzel et al. 2013), serves as geometric input.

The geometric characteristics of the Nefertiti bust have to be rated as unsteady and complex. In order to adapt the dataset to a typical measurement volume of TLS, the 3D-model has been scaled to a width of 2.4 m, a depth of 3.5 m and a height of 4.9 m. In this example nine viewpoints have been simulated ranging from 8 to 22 metres which are roughly 1.6 m apart.

Ray casting has been conducted from every viewpoint which lead to simulated point clouds. For every simulated point incidence angle, object distance and radiometric properties on the object's surface were computed which leads to a signal deterioration. Based on this information the achievable precision in the field is derived. The quality of a viewpoint is computed based on the average spatial precision of all simulated points.

Figure 2 illustrates the outcome of the planning process where spheres represent all potential viewpoints. The colours of the spheres denote their respective average precision while the colour bar is given in millimetres. It can be seen that the precision drops with increasing distance. The optimal viewpoint in this example is the closest one to the object.

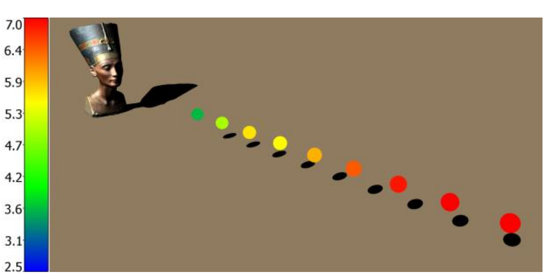

Fig. 2 Potential viewpoints (coloured spheres) and 3D-model

4 Summary and conclusion

The article at hand describes a novel stochastic model for the distance measurement unit of TLS where intensities are the only input parameters. This model allows to reliably estimate the achievable precision of 3D-points for the first time that considers the acquisition configuration and the radiometric properties of the object's surface. Based on a 3D-model viewpoint planning was conducted that identified the optimal acquisition configuration.

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