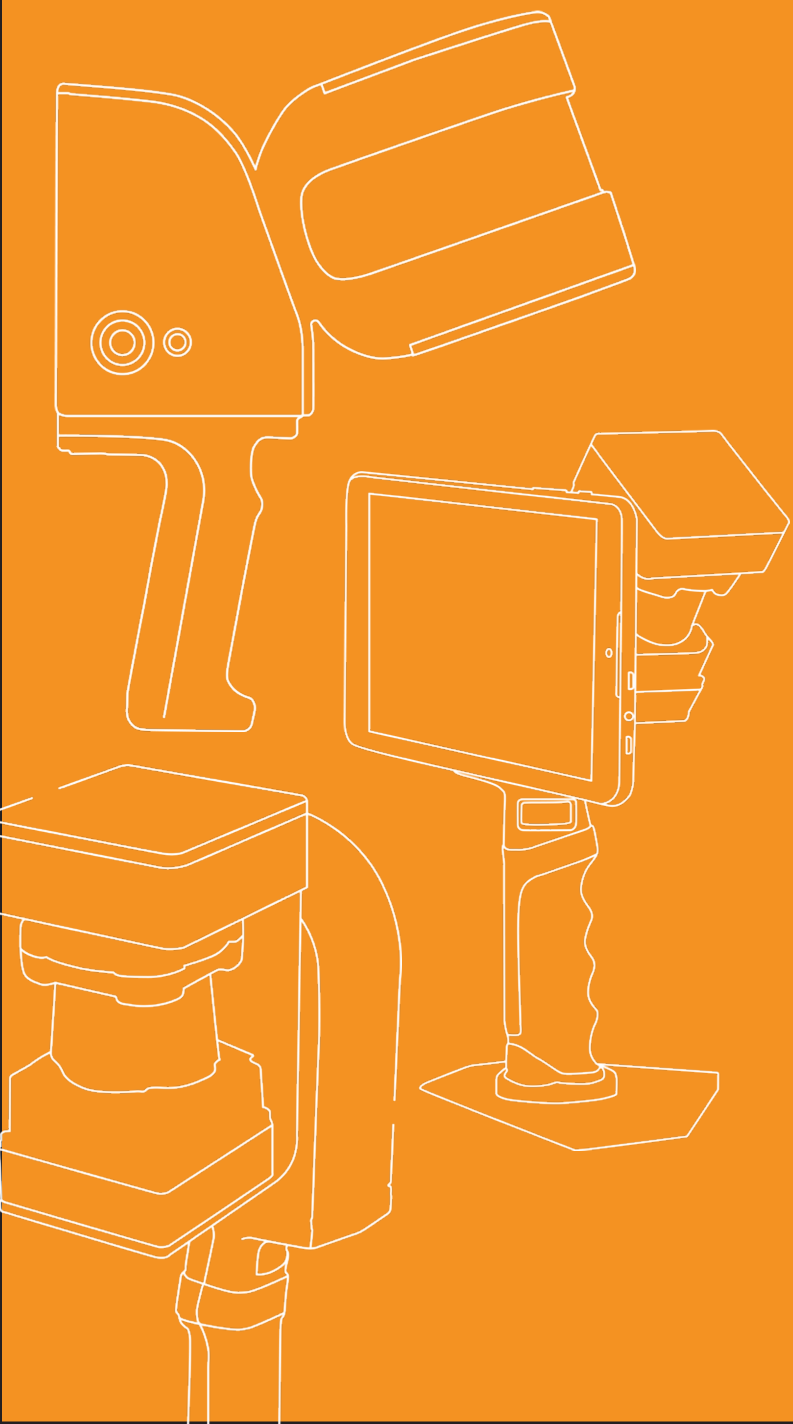
Accuracy Report

Assessing the performance of GeoSLAMs handheld laser scanners



We investigate the accuracy of GeoSLAM ZEB Handheld Laser Scanner systems by determining differences in point cloud measurements. We use two methods to determine accuracy. The first method involves point-to-point measurements, and the second method compares the complete point clouds. The results indicate that the GeoSLAM systems compare favourably in comparison to stationary measurements with traditional LiDAR based survey instruments and exceeds other SLAM based mapping systems using the Velodyne VLP-16 sensor.

Introduction

GeoSLAM instigated the development of the first commercially available handheld Simultaneous Location and Mapping (SLAM) based laser mapping system by launching the ZEB in 2012. Since then, GeoSLAM has continued to be a leader in the Handheld Laser Scanning (HLS) market in terms of system innovation and solution robustness in increasingly challenging capture environments and customer focused solutions.

The increase in popularity and reliance on laser mapping (LiDAR) solutions across multiple sectors, such as construction, mining, and infrastructure mapping, has seen an increasing number of companies entering the HLS market. Purchasing a HLS can therefore be a difficult task. Available systems come with a range of different sensors to use and the choice of the right system with the correct sensors is critical for a successful project outcome and ultimately the success of a company. Complicating this task, is that the accuracy of a SLAM based mapping system is not only determined by the accuracy and precision of the sensing device but also, and potentially more importantly, by the software used to create the map.

This document provides information on the performance of two of the GeoSLAM HLS systems, the ZEB Revo RT and the ZEB Horizon.

Background

LiDAR is an established active optical remote sensing technique. It has proven to be a powerful surveying tool across a wide variety of sectors for over 40 years. It has been used on spacecraft, airborne, marine and terrestrial-based platforms.

Traditional ground-based LiDAR systems are tripod-based that can produce millions of data points with sub-mm to mm accuracy and are often used for localized terrain-mapping applications that require frequent surveys. Modern navigation and positioning systems enable the use of water and land-based mobile platforms to create survey-grade mapping data. Data collected from these platforms are highly accurate and are used extensively to map discrete areas, including railways, roads, buildings, utility corridors, harbours, and shorelines. Mobile Laser Scanning (MLS) systems have the benefit over Terrestrial Laser Scanning (TLS) systems of being able to acquire large complex areas more quickly and efficiently. However, their reliance on high quality, positional data, typically from GNSS, makes them poorly suited for indoor or GNSS deprived environments.

In these environments HLS systems, coupled with SLAM algorithms, have successfully been used to collect mapping-grade data that can be used for rapid floorplan creation in infrastructure mapping, time-lapse construction progress management, volumetric stockpile management and many more.

SLAM

Mobile Laser Scanning systems typically consists of various sensors including a high-grade inertial measurement unit (IMU), global navigation satellite systems (GNSS) and laser scanners. The laser scanner typically uses a rotating mirror on a 2D plane. To measure in 3D, the scanner must either rotate or move along a trajectory. The scanner orientation and position along the trajectory is determined from the combination of the output from the inertial measurement unit and the global navigation satellite systems. By fusing the laser data (in the form of an angle and range from the scanner) with the independently derived trajectory a 3D map is created.

SLAM based scanning systems, again, use a 2D scanner that rotates and moves along a trajectory. The 3D map is created only using the laser measurements it acquires and a low-grade IMU. No GNSS or other environmental infrastructure is required. At a single point in time the system records a 3D map of its immediate environment. As the sensor moves, an algorithm is used to merge the successive overlapping maps, utilizing the presence of distinct features such as edges in the environment to establish correspondences between each map. While the sensor is moving and acquiring these maps, the algorithms use sensor measurements to map the environment and locate the sensor within that map. This process for analysing the range data to build a map and determine localization is known as Simultaneous Localization and Mapping or SLAM.

There are many factors which must be considered that can affect the overall quality of the resultant 3D map.

Conditions that can potentially affect data quality in real world measurements include:

- ✓ The environment: are there strong features to establish correspondence
- ✓ Atmospheric effects: is there a lot of dust/rain
- ✓ Surface materials and textures: dark, wet surfaces are poor energy reflectors

In the case of laser:

- ✓ Laser beam divergence: divergence forms a larger spot at greater distances
- ✓ The resolution and precision of the instrument may be very good but there is a vast amount of data, hundreds of thousands of points, which are low-pass filtered to mitigate the noise.

From even this limited list of factors it is possible to see that the accuracy specification of the instrument is only a starting point in understanding the accuracy of the measurement process.

Terminology

When gauging system quality, manufacturers will specify a number of data metrics. The most widely used are accuracy and precision. Measurement accuracy is most universally defined as the degree of conformity of a measured quantity to its actual (benchmark) value, and precision as the degree to which further measurements show the same result. Clearly, when assessing accuracy, a secondary measurement system must be used to provide the benchmark value and this system must be of greater accuracy than the system under test. When assessing a Handheld Laser Scanning system, the industry standard is to utilise either a laser distance measurer (LDM), total station (TPS) or a terrestrial laser scanner (TLS).

Other terms which are often discussed are local and global accuracy. However, these terms are more ambiguous in their definition. With respect to HLS, local accuracy relates to the distance between 2 points in the cloud, where the object can be viewed from a single position, e.g., the dimensions of a single room. Global accuracy relates to the distance between 2 points in the cloud, where the object cannot be viewed from a single position, e.g. the distance between 2 rooms.

Accuracy Assessments

To evaluate both local and global accuracy of ZEB HLS (Revo RT and Horizon), measurements were compared with two industry standard devices; a Laser Distance Measurer (LDM) and a Terrestrial Laser Scanner (TLS). These devices were chosen as references as their published accuracy is greater than the comparison data from the HLS.

Assessing Local Accuracy using an LDM

A measure of local accuracy (the distance between two points captured by the HLS at a single location, e.g., within a room) is an important metric for users wishing to create 2D floorplans or 3D building models from a point cloud. A series of target boards were distributed throughout the test area and the centre-to-centre distance measured with the LDM. These points were identified in HLS point cloud data and the centre-to-centre distance extracted and compared.

Assessing Global Accuracy using a TLS

A more appropriate measure for assessing overall system accuracy, and in particular global accuracy is to conduct a full comparison of the TLS and HLS point clouds computationally. This will highlight deviations across the whole cloud. This comparison was conducted using an implementation of the Multiscale Model-to-Model Cloud Comparison(1). The key characteristic of this method is that:

- It operates directly on the point clouds without meshing or gridding.
- It computes the local distance between two point clouds along the normal surface directions which tracks 3D variations in surface orientation.
- It estimates for each distance measurement a confidence level depending on the point cloud registration error and cloud roughness.

Whilst every effort was made to ensure that the environment remained unchanged between scans, we include deviations up to 50 mm in the analysis, data above this limit was considered as an outlier.

Comparing TLS and HLS Accuracies

When analyzing and comparing data from a TLS and an HLS it is important to note the key differences in how the data is captured. TLS data is captured from individual positions and points matched (registered) from groups or clusters of positions. HLS systems by the very nature continuously capture data at multiple positions as the operator passes through the environment.

TLS manufacturers, therefore, refer to the accuracy of the instrument from a single measurement position and at a specific confidence level. The confidence level is associated with standard deviation. Riegl state that the VZ-400 has an accuracy of 5mm at 1 sigma, which means that 68% of all measurements have to be within a range of 5mm. 2 Sigma values mean that 95% of all measurements must lie within a given range. To compare data from the HLS these two confidence levels will be computed.

Test Environment

To assess the local and global accuracy of both the ZEB Revo RT and ZEB Horizon, a series of scans were taken in a typical UK domestic residence.

LiDAR control boards were placed at 8 discrete positions around the house. The boards were positioned to create 5 pairs for point-to-point comparisons.

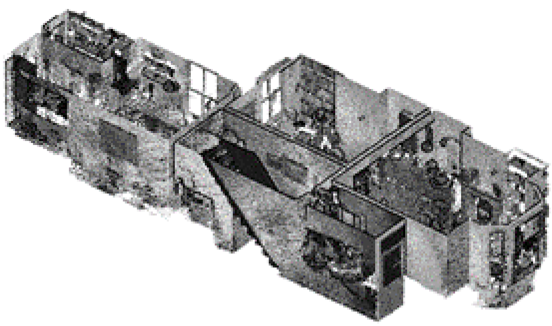


Figure 1. Ground floor pointcloud of the test area.

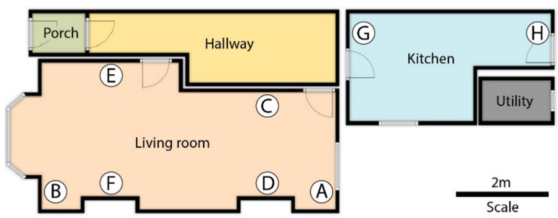


Figure 2. Location of LiDAR control boards

Prior to any scans with the HLS systems a reference scan of the building was carried using a Riegl VZ-400(2) TLS. To aid registration of the data, standard survey spheres (145mm diameter) were placed through the area. Data processing and registration was undertaken using RiScan Pro V2.11. Data was output at 1mm spatial decimation.

All HLS data was processed using GeoSLAM Connect V2.0. Data were exported in LAZ format using a 1mm spatial decimation to match the TLS data. Both datasets had a Statistical Outlier Filter applied prior to the cloud-to-cloud computation to remove outlying noise. Additionally, the ZEB Horizon LiDAR Sensor (Velodyne Puck VLP-16) data were processed against a proprietary calibration function prior to data analysis.

Point-to-Point measurements between the 5 pairs of parallel control boards were taken using a Leica DistoTM D110(3).

Test Results

Assessing Local Accuracy using an LDM

The location of the Point-to-Point measurements is shown in Figure 2. Point-to-Point distances for the targets from the ZEB Revo RT and ZEB Horiz on data were extracted and the differences from the LDM are given in Table 1.

Point-to-point local accuracy	ZEB Revo RT	ZEB Horizon
Point A to B	5mm	6mm
Point C to D	8mm	11mm
Point E to F	3mm	10mm
Point G to H	1mm	12mm

Table 1. Distance comparison between the LDM and the ZEB Revo RT and ZEB Horizon for LiDAR control board pairs.

Global Accuracy Assessment

The cumulative distribution of the deviations between the TLS point cloud and the ZEB Revo RT and ZEB Horizon point clouds are shown in Figure 3 and Figure 4. The plots indicate that for the ZEB Revo RT the global accuracy is 6mm at 68% confidence and 15mm at 95% confidence. For the ZEB Horizon, the global accuracy is 6mm at 68% confidence and 19mm at 95% confidence.

Absolute Accuracy Global Cloud-to-Cloud	ZEB Revo RT	ZEB Horizon
68% of Measurements are below	6mm	6mm
95% of Measurements are below	15mm	19mm

Table 2. Absolute Accuracy Statistics.

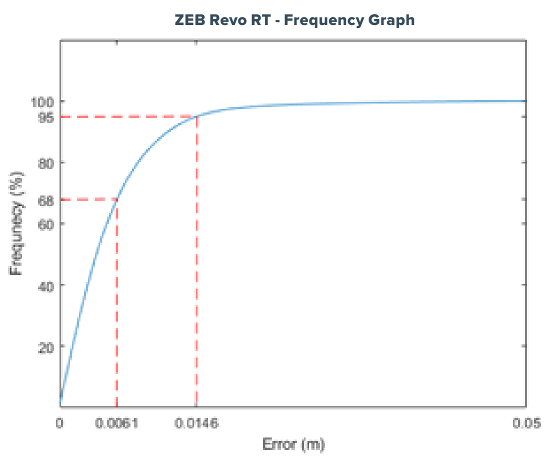


Figure 3. Cumulative distribution of deviations resulting from the Global Cloud-to-Cloud comparisons for the ZEB Revo RT.

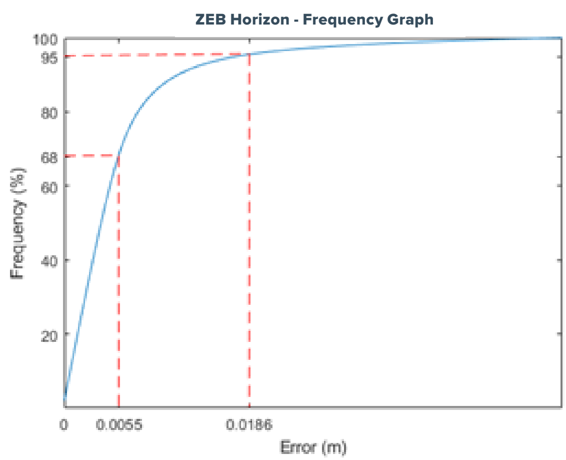


Figure 4. Cumulative distribution of deviations resulting from the Global Cloud-to-Cloud comparisons for the ZEB Horizon.

Conclusion

Measurements were undertaken in a typical UK residence using a ZEB Revo RT and a ZEB Horizon Handheld Laser Scanner system. Data was compared against traditional LiDAR based survey instruments, which were a Leica DistoTM D100 and a Riegl VZ-400 Terrestrial Laser Scanner.

Data from the ZEB Horizon were prepared using Connect V2.0 (utilising the integrated laser calibration function and point filtering module) without using an external control adjustment.

Analysis of the data shows that for point-to-point measurements the ZEB Revo RT gives a mean accuracy of 5mm±3mm and the ZEB Horizon gives a mean accuracy of 6mm±4mm.

When analysing the overall cloud-to-cloud measurements then the ZEB Revo RT achieves a 1-sigma accuracy of 6mm and 15mm at 2-sigma. The ZEB Horizon achieves a 1 sigma accuracy of 6mm and 19mm at 2-sigma.

These results confirm that GeoSLAM's proprietary Simultaneous Localization and Mapping (SLAM) algorithms enable GeoSLAM to achieve a level of accuracy that (a) meets mapping requirements and (b) exceeds other SLAM based mapping systems using the Velodyne VLP-16 sensor at 1-sigma.

References

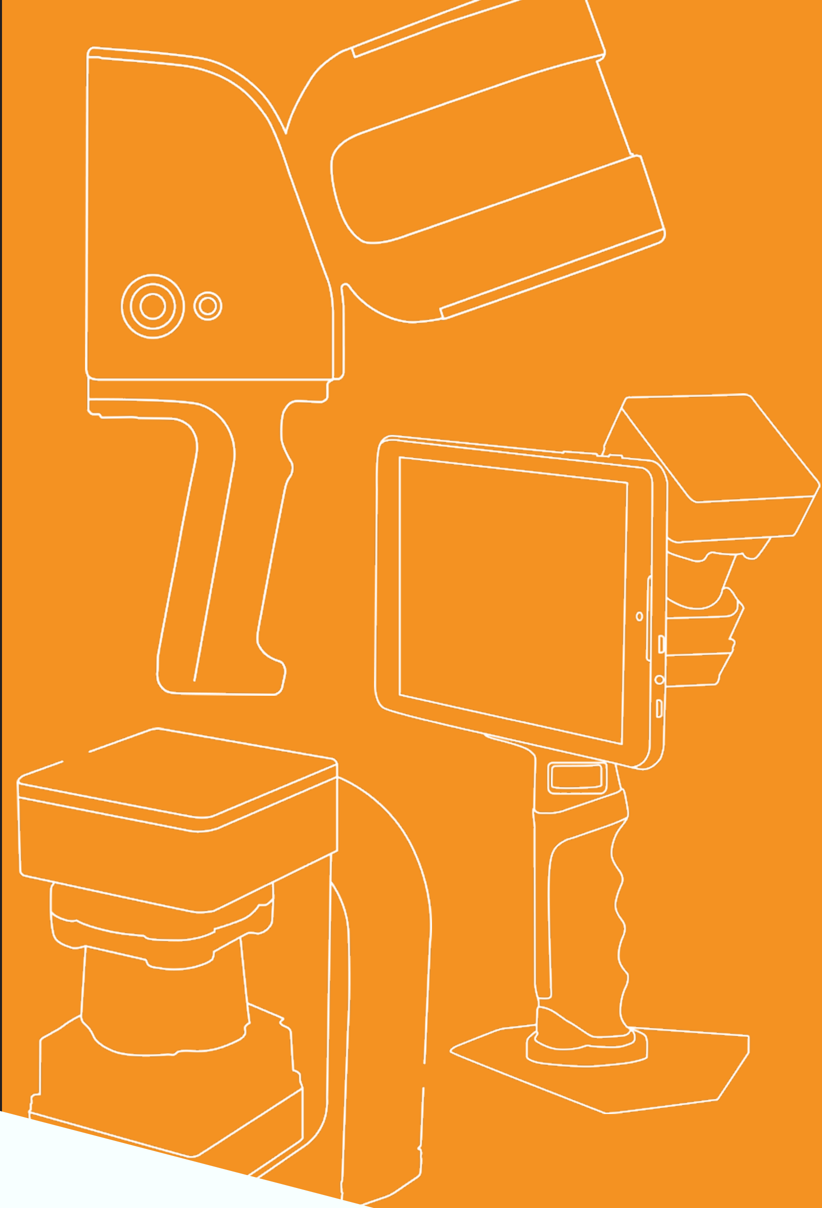
[1] Dimitri Lague, Nicolas Brodu, Jerome Leroux: Accurate 3D comparsion of complex topography with terrestrial laster scanner: application to the Rangitikei canyon (NZ). ISPRS Jounrnal of Photogrametry and Remote Sensing, Volume 82, August 2013, P10-26.

[2] Riegl VZ400. DataSheet: VZ-400_2017-06-14.pdf.

[3] Leica DistoTM D110. Manual: Leica-DISTO-D110-Manual.pdf.

[4] Velodyne Puck, Datasheet: 63-9286_Rev-K_Puck-LITE_Datasheet_Web.pdf

[5] U.S. Institute of Building Documentation: USIBD Level of Accuracy (LOA) Specification Guide, 2016, available via https://usibd.org/



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