5/9/2023
Version 1.0

Ground Control Points and Targets LP360

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GROUND CONTROL POINT (GCP)

A Ground control Point (GCP) is a monumented point for which geodesic coordinates are known with a controlled accuracy and precision. It can be provided by a National Geodetic Authority or made by the user.

Several topographic survey techniques can be used to determine the coordinates of a GCP (GNSS, geodetic network adjustment from distance, angle measurement, etc.).

A LiDAR Ground Control Target (GCT) is a device that has a defined a unique center. The set of LiDAR points that impact the GCT can be used to determine this center.

We shall call the Computed GCT Center, the center of the GCT device, uniquely computed from the LiDAR points.

In comparing the Computed GCT Center and the coordinates of the GCP we can assess the deviation from the local point cloud to the GCP at the GCP location: Thus, we can compute the LiDAR point cloud accuracy. It is important to check that the estimation of the center of the GCT is conducted with sufficient accuracy. Indeed, if the center position estimation was uncertain, we could not compare with the reference GCP position. Conversely, we note that if the quality of the reference GCP position is not good enough, it cannot be used for accuracy assessment.

WHY USING LIDAR GCTS ?

LiDAR GCTs are designed to enable the user to compute the separation between a reference point and the same point as described by the LiDAR point cloud. The reference point is described in the point cloud by the points representing a geometric or an optical target. From these points we can assess the separation between the LiDAR point cloud and the reference point.

The estimated separation (i.e., the estimated accuracy of the point cloud) is only valid locally, around the GCP. It may not describe the global survey accuracy.

Indeed, the LiDAR accuracy may depend on several systematic biases acting on the LiDAR system and on the computational workflow used to georeference the LiDAR points. Examples include:

- boresight angles,
- lever-arms,
- geodetic transformation bias (datum shifts),
- IMU heading bias, etc.

For a medium or large-scale project, it may be useful to install several GCTs to make accuracy estimations at different locations. These locations should be chosen to represent areas of interest or areas on which the LiDAR system could be submitted to a different bias.

For example, for a long corridor survey, the GCTs should be installed at the beginning and at the end of the corridor to measure the effect of IMU heading bias along the corridor, especially if the UAV is flying at low speed.

It should be mentioned that GCTs do not represent the terrain, as they are by essence artificial targets. Therefore, we cannot estimate a LiDAR bias on different reflectance material for instance, as **the points used are from the GCT, not from the underlying ground.**

It is also important to differentiate accuracy (bias) from precision (noise). Precision can be estimated by a standard deviation (on Z, or along the terrain's normal), but accuracy must be derived from a reference (external measurement) point.

An interesting usage of GCT is to analyze if the accuracy depends on the survey strip under consideration. Indeed, if a GCT is installed on a strip overlap, we can compute the estimated GCT center for the overlapping strip taken separately, and for the whole set of strips. This analysis may indicate the presence of strip dependent bias.

2D LIDAR GCTS

GCPs were first used in photogrammetry to achieve the same goal: What is the deviation between a GCP and an orthophoto produced by a photogrammetry process? The most common target used in photogrammetry for UAV collected data is the checkerboard. Another 2D Target is the concentric circle.

**Figure 1: Left: Checkerboard, directly inspired from photogrammetry.
Right: Concentric circle adapted to LiDAR.**

Due to the LiDAR footprint effect, the LiDAR point intensity is not only black or white but a mix of intermediate grey values. This is illustrated in the next figure in the case of a checkerboard:

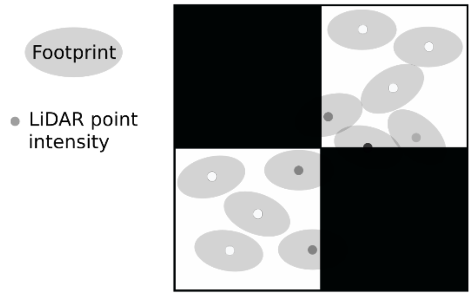


Figure 2: Due to the footprint effect, at the frontier between black and white, the returned intensity is generally grey. Black and white squares boundaries may not be clearly described from the LiDAR point cloud.

As a result, the point cloud describing the targets is typically as illustrated above. Therefore, the estimation of the center is dependent upon the sampling of low and high intensity (black and white) points over the target.

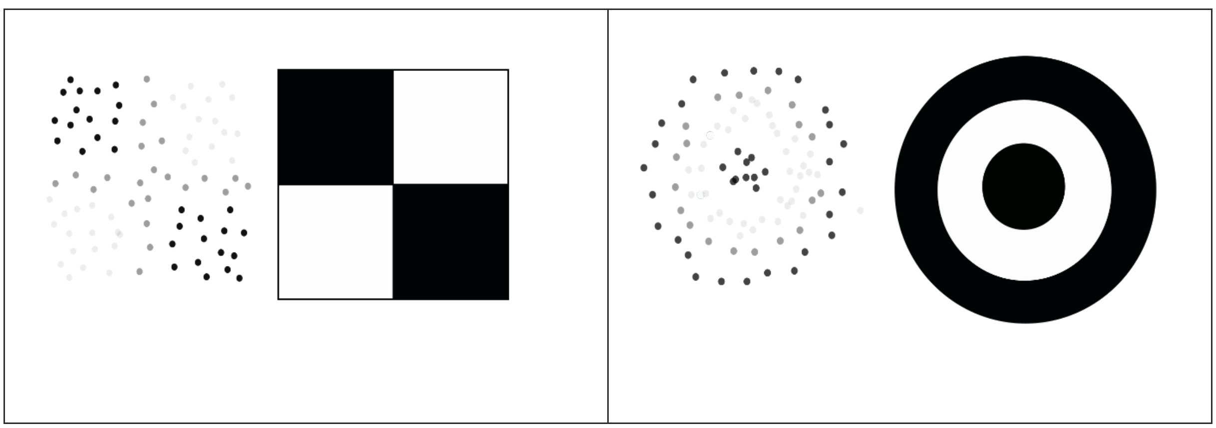


Figure 3: Left Checkerboard and typical LiDAR point intensity. Right: Concentric Circle and typical point intensity.

Another drawback of 2D targets lies in the fact that they give the X, Y estimates of the center. The Z value has to be estimated by a spatial interpolation on a neighborhood of the estimated center.

Estimating the point cloud accuracy using 2D-GCTS assumes that the estimation of the center of the GCT is done with a very good accuracy. Center coordinate estimates are submitted to uncertainty whenever the LiDAR point sampling is irregular over the circles or squares.

The limitations of 2D targets can be overcome by the use of 3D GCTS, like the "Accuracy Star".

However, 2D GCTS are simple to install on the field and can play the role of "secondary" targets for large scale surveys.

3D LIDAR GCTS

The Accuracy Star is a 3D GCT forming a regular hexagon located above the ground. Six hexagonal reflectors are fixed on the tips, each tip being on the same planar surface. Whenever we gather a minimum number of LiDAR points on the reflectors, we can fit the planar surface and then adjust the center of the hexagon.

The main features of the Accuracy Star are:

- Arm length 70cm
- Reflector diameter 14cm
- Recommended installation height: at least 140m.

Figure 4: Accuracy star installed on a tripod with a GNSS receiver at the center. The reference position of the GCP is given by GNSS processing. The reflectors are used to compute the geometric center of the hexagon from the LiDAR point cloud.

There are two different ways the Accuracy Star can be used.

- When placing a GNSS antenna at the center we can make a GNSS estimation of the center in 3D. This point will play the role of reference coordinates of the GCP.
- When installing the Accuracy Star over a survey nail or a monumented GCP by levelling the tripod. In this case, the vertical separation between the survey nail and a reference height of the Accuracy Star should be measured accurately.

The main advantage of the Accuracy Star is to provide a precise, unbiased and 3D deviation of the point cloud with respect to a given GCP:

- It is accurate since the hexagon geometry allows to estimate the center from 3 to 6 clusters of points representing the reflectors. Redundancy in the hexagon observation makes the center estimate precise and robust. The size and the separation of the reflectors has been optimized to allow good detection for most UAV LiDAR flight configuration.
- It is unbiased since the redundancy of the six reflectors allows us to estimate the center in a robust way.
- The Z component comes from the vertical separation from the ground of the reflectors. It is important to install the Accuracy Star at the highest possible elevation from the ground.

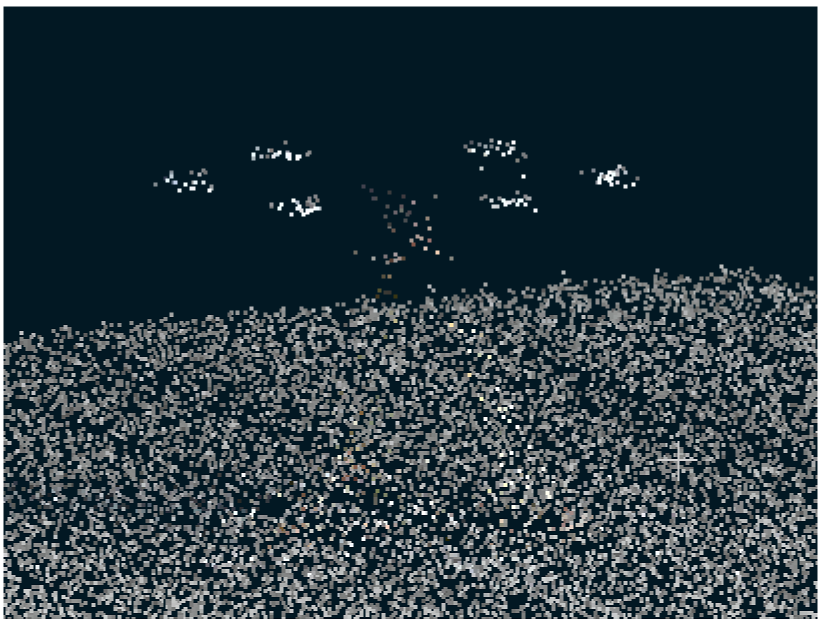


Figure 5: Accuracy Star as seen by a TrueView 515 system. We can clearly distinguish all the reflectors. The vertical separation from the ground enables us to estimate the 3D position of the target.

EXAMPLE WITH MULTIPLE LINES:

We see in the example below that each line is shifted from the other, indicating the presence of either a systematic error or a dynamic error. This is an illustration of how Accuracy Star can help the user to understand the global accuracy from the accuracy of each strip.

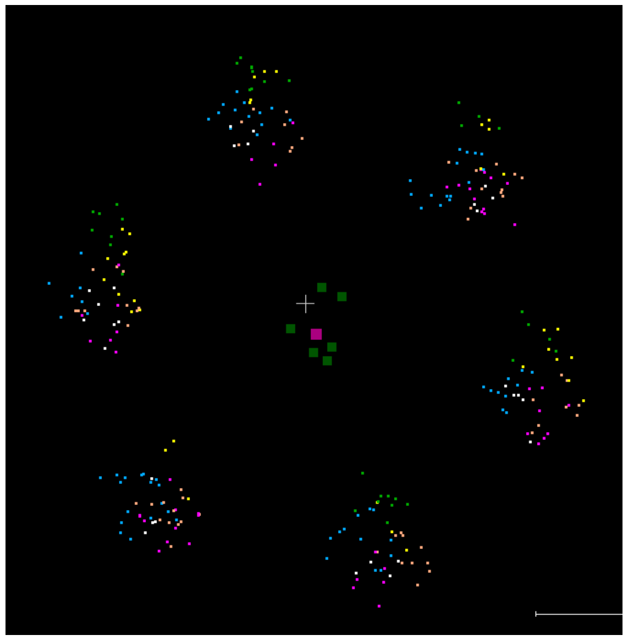


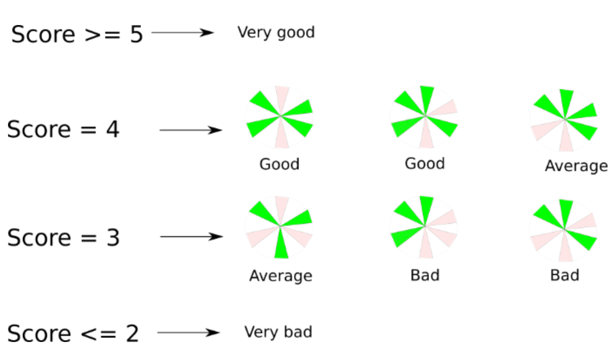
Figure 6:Each Accuracy Star Reflectors is plotted with a given color for each flight line. We see that each line is shifted from the other. The larger green points are the computed center of the Accuracy Star for each line. The pink point is the center point computed from all lines.

QUALITY INDICATOR OF THE ACCURACY STAR CENTER ESTIMATION

To check that the Accuracy Star quality is good enough to make a relevant comparison with the GCP position, and further point cloud correction, we define the following quality indicators;

- QI1: Comment on the quality of GCT
- QI2: Isotropy of the points from the six reflectors: Indicates if the hexagon if sufficiently well described to estimate the center.

QI2 is defined as follows:



Reliable results	GCT is correctly estimated
"Noise warning"	The estimated GCT center could be used for point cloud correction. Check consistency of computed offset with other GCT if possible.
"Noise alert"	Estimated GCT center location must not be used for point cloud correction. Check reference GCP position and vertical offset of GCT w.r.t. GCP.
"Low density warning"	Estimated GCT center should not be used for point cloud correction. Use if computed offset is consistent with other GCT/GCP offsets. Check reflector description within point cloud.
"Low density alert"	Estimated GCT center location is not reliable for point could correction. Accuracy Star description within point cloud is not good enough.
"Not useable"	GCP neighborhood does not contain any Accuracy Star.
"Not enough points"	GCP neighborhood does not contain enough points.
"Not enough detected reflector points"	GCP neighborhood does not contain enough reflector points

Table 1.

COMBINING GCTS

To cover a survey area, we can combine GCTs to achieve specific goals. The different targets we can combine are:

- 2D GCTs (checkboards or concentric circle): They will give the XY deviation and a rough estimate of the Z deviation on the basis on interpolated points
- Accuracy Star with GNSS
- Accuracy Star without GNSS over a survey nail or a monumented GCP.

The best estimate of the 3D accuracy will be given by either an Accuracy Star with a high quality GNSS estimation or over a high quality monumented geodetic point. Remind that the quality of the external measurement to define the reference coordinates of the GCP is of the same importance as the quality of the GCT center estimation.

It is recommended to deploy at least 3 GCTs to enable a possible rotation-translation transformation.

Number of AS	1	2	3+
Translation	Yes	Yes	Yes
Rotation + Translation	No	No	**Yes**

Table 2.

One GCT allows validation of the point cloud Accuracy and confirms that the dataset does not have major issues. The point cloud cannot be corrected locally but can be validated within the expected accuracy range of the system. Installing at least one Accuracy Star in the survey area is therefore recommended. To supplement it, Accuracy Stars over survey nails are a good compromise between the simplicity of installation and quality of the LiDAR GCT LCGT center. Accuracy Star can also be supplemented by 2D GCTs for which we can estimate (or not) the Z component.

SUMMARY

3D GCTs are efficient and easy to use tools to get an 3D unbiased estimate of their center. In computing the separation between the center and the reference GCP we get an estimate of the local accuracy of the LiDAR survey.

Covering the survey area by secondary GCTs (survey nail Accuracy Stars or 2D GCTs) will allow the user to consolidate the validation process of the LiDAR survey data quality.

The computed separations between GCTs and GCPs can be used by point cloud rigid or non-rigid registration tools to adjust the point cloud to the available GCPs.

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