GROUND CONTROL REQUIREMENTS FOR POST PROCESSING AERIAL IMAGERY

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Version 5

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11/1/2022	1	Initial document	N. Edmead
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Definitions, Acronyms and Abbreviations

The following are contained within this report:

ASCII	American Standard Code for Information Interchange
CORS	Continuous Operating Reference Stations
CRS	Coordinate Reference System
CSV	Comma Separated Values
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GSD	Ground Sample Distance
ITRF	International Terrestrial Reference Frame
PPK	Post-Processed Kinematic
RTK	Real-Time Kinematic
SFM	Structure from Motion
WGS84	World Geodetic System, 1984

About this document

This document is intended to guide Government partners in the establishment of Ground Control Points (GCPs).

GCPs are used to geo-reference and validate aerial images, orthophotos and three dimensional models created from aerial images. They consist of **well-defined physical point features** which are:

- clearly and unambiguously identifiable in aerial imagery and
- for which precise three-dimensional geographical coordinates (Lat, Long, Height on an established datum and reference surface) or projected orthogonal coordinates (X.Y,Z or E,N,U on a well-defined coordinate system) are available.

Intended audience

This document primarily serves as a reference for those persons conducting ground control campaigns by describing how they should be captured and recorded.

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Introduction

Ground Control Points (GCPs) are needed to validate the accuracy of the map and to provide for some contingency for geo-referencing in case accurate GNSS PPK positions of the camera exposure positions are not available.

Why collect GCPs

GCPs are used for the following purposes:

- to geo-reference and adjust aerial triangulation results; and
- to validate the accuracy of orthophotos and three dimensional surfaces derived from aerial imagery.

Their accurate coordinates are commonly determined using accurate kinematic GNSS methods (GNSS CORS, GNSS Network Service, RTK/PPK GNSS base/rover - GNSS RTK or PPK usually suffices). To ensure that the aerial imagery and mapping products derived therefrom can be correctly overlaid on other geospatial information it is imperative that GCP coordinates must be referenced to a well-defined spatial reference frame. Examples of such reference frames are the International Terrestrial Reference Frame (ITRF), the World Geodetic System of 1984 (WGS84 - on which GPS is based) and any well documented national or international datum such as the North American Datum (NAD), the European Terrestrial Reference System (ETRS), the Indian Geodetic Datum or the South African Hartebeeshoek94 datum. Any coordinate datum for which sufficient geodetic information has been established to reliably transform coordinates to that of another common known and defined datum should qualify as an acceptable datum.

Note that official coordinate systems comprise of a datum element as well as a projection element. For example, unprojected coordinates in a particular datum can be in the form of geo-centered orthogonal (XYZ) or geographic (Latitude, Longitude, Height above ellipsoid) or they can be in the form of much more user-friendly projected rectangular coordinates which can be readily mapped on two-dimensional grid patterns.

Coordinate projections are either “equal area” or “conformal” - they cannot be both. Equal area projections ensure that areas are projected proportionally to their true sizes, thereby distorting the shape. Conversely conformal projections maintain correct shape at the expense of correct area proportionality. Each country typically defines its particular coordinate system or systems so as to minimize inevitable distortions resulting from the projection of a curved surface onto a flat surface. For example Chile, which has a small range in longitude but a huge range in longitude can adopt a few Gauss Conform coordinate systems while South Africa, with a considerably larger extent in the east-west direction, uses 10 adjacent Gauss Conform Projections (named Lo Systems) each of which is two degrees wide and centered on an uneven longitude (i.e. 15 to 33 degrees East). Giving a set of projected coordinates XYH without specifying the particular Lo system could thus be a position in any one of the 13 Systems. To remove this ambiguity it is thus necessary to specify datum as well as projection as described above.

For an authoritative identification of a particular coordinate system one can consult www.spatialreference.org which hosts a list of all common spatial reference systems in the world.

Additional GCPs, sometimes referred to as validation points) are needed to certify the spatial accuracy of ortho-mosaics and surface models. To satisfy a confidence level of 95% in the spatial accuracy certification of an SfM derived map or model a minimum number of 19 validation points are needed. They should be evenly distributed over the mapping area. The same guidance for collecting GCPs should be followed but the choice of point features should reflect the purpose of the model. For example, if the purpose of an ortho photo is to vectorize the roof outlines in an urban environment then the validation points should

predominantly be roof corners. Similarly, if the subject of interest is sewer manholes, then the validation points should be sewer manholes. For certain projects it may thus be necessary to provide a minimum of 19 validation points for each of the features of interest.

How many Ground Control Points should I collect

As a general rule of thumb five (5) GCPs are required per square kilometer[1]. Imagine laying a 1 by 1 square kilometer grid over the area being flown, GCPs would be collected at the 4 corners and center of the grid. If you are collecting over a larger area where GCPs are coincident only one point is collected:

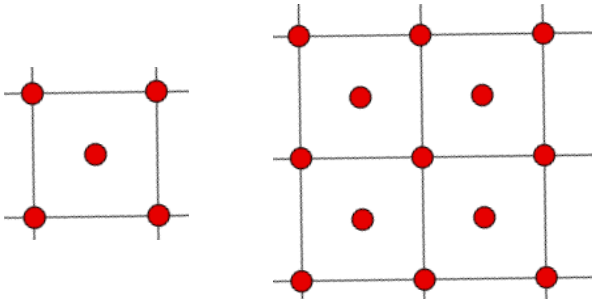

Figure 1: For a 1 sq. km grid collect 5 points (L), if more than 1 sq. km (R) then duplicate intersection points can be omitted from the collection campaign.

Use the guidance in this document to identify suitable GCPs, the above simply refers to how many GCPs are required not where they should be collected. Below is an example of a GCP campaign conducted for an area of 25 sq km in Abidjan:

[1] Wingtra recommend 4 per sq mile; see: https://wingtra.com/ground-control-points-how-many-do-you-need-and-when-are-checkpoints-enough/

Requirements for collecting Ground Control Points

Persons responsible for collecting GCPs should note the following collection requirements:

- As much as possible use should be made of **suitable existing features** on the ground. This will ensure that you do not have to create targets (typically done by painting crosses on flat surfaces) and subsequently maintain them for the duration of the image acquisition campaign and beyond). Targets should also be of a permanent nature not only to re-survey a point in case of uncertainties but also to re-utilize the point for future projects.
- All artificial targets should be of **durable** nature so that they are still well visible from the air by the time the flights are taking place.
- It is essential that for each point a picture unambiguously defining the exact feature being surveyed is delivered. The picture file name should indicate the point number being surveyed.
- When choosing a specific part of a feature make sure it is **well defined**. To remove any ambiguities as to which feature exactly was surveyed, take **three illustrative photos** of the target at the time that it is occupied by the survey rod – i.e. showing the survey rod on the target. To avoid confusion it is very good practice to let your cellphone **geo-tag the photos**. That way you can unambiguously link the photos with corresponding targets. For example the north- western corner of a painted stop bar at a road intersection is a well-defined point; the center of a large manhole however is not because it relies on guess work by the surveyor as well as the person who is going to observe the target in the imagery. Similarly, the outer apex of a V-shaped target is better defined than the intersection of two lines forming a cross. Well composed cellphone pictures give a much better definition of the exact location of the target than a verbal description can do. However, where necessary **verbal descriptions** should be used to augment the documentation.



- Targets should preferably be on **flat ground**. We depend very much on the **three-dimensional definition** of the target. So if a target is suitable for horizontal purposes make sure that there is no ambiguity as to exactly where the height of the target was referred to. For example, if you choose a corner of an elevated concrete slab make sure that there is a record of whether the height refers to the top of the concrete surface or to ground level at the corner.
- If the area has noticeable **elevation changes** place GCPs at the highest and lowest points.

- Targets should be **visible from** as **low** a **horizon** as possible. Targets near trees or buildings will be obscured from several aerial camera positions. We want the targets to appear on as many of the aerial images as possible. When installing targets in parking lots bear in mind that parked cars may obstruct a target during the course of the image acquisition flights.
- The best **contrast** is provided by **black and white**. Green and white – such as a white cross on a green lawn is also very good. Orange and red are bad colors because they tend to "run" in the images. So don't use orange when you spray a cross on asphalt. Rather use white.
- **Edges** of lines or figures used in the definition of a target **should be sharp**. Spray cans without the use of templates produce fuzzy edges.
- The **resolution** of PLACE images are generally 5cm or less. Targets should be detectable at that resolution. If, for example you want to paint a cross or a V on asphalt, make sure that the arms of the cross or V are 6cm wide. Circular or square targets should have a diameter/side of about 15cm.
- Target coordinates should be as **accurate** as practically possible. We will be sensitive to target errors of less than 3cm. The used semi or fully automated software for orthophoto production (SFM or SGM) demand a very high quality level of the input data, like the GCP. Best results we achieve, when the GCP´s are measured with an accuracy of ¼ to 1/3 of the desired resolution of the orthophoto (i.e. 5cm orthophoto –> GCP accuracy 1.25 to 1.6cm). GNSS RTK or PPK usually suffices but it is important to **survey each point at least twice** and to accept **only fixed solutions**.
- Unless you are 100% sure that your **rod bubble** is in perfect **adjustment** you must take 2 measurements per occupation. To eliminate the bubble error provide two measurements with the rod turned 180° between the two measurements. The mean of the two measurements will be free of bubble misalignment. Note that a pair of measurements of this kind are considered as a single measurement of the point.
- All the points **MUST** be on the **same coordinate system**. Unless the chosen coordinate system is well defined in relation to WGS84 or any of the ITRF epochs, a separate survey will be needed to establish **transformation parameters** between the chosen system and WGS84/ITRF. The tools for aero triangulation and orthophoto production demand the use of a non projected, Cartesian CRS (coordinate reference system) otherwise the scale factors of the projected CRS (i.e. UTM) will cause distortions in the final products. *Therefore the best way is to measure the points directly in WGS84 or any of the ITRF epochs. The elevation reference should be ellipsoidal*.

What format should I provide GCPs in

A list of ground control points (GCP) should be provided as an ASCII text file (comma separated values or CSV format) with the following information:

ID	Easting/Long	Northing/Lat	Height	Desc	Photo_1	Photo_2	Photo_3
The ID of GCP (name or number)	***Easting or Longitude***	***Northing or Latitude***	***Elevation***	***Short description of the GCP***	***File name of 1st geotagged photo***	***File name of 2nd geotagged photo***	***File name of 3rd geotagged photo***
W6065	-72.282668898	21.741011608	5	Control on Harbor Road	DSC0001.jpg	DSC0002.jpg	DSC0003.jpg

e.g.

```
ID,Long,Lat,Alt,Desc,Photo1,Photo2,Photo3
W6065,-72.282668898,21.741011608,5,Control on Harbor Road,DSC0001.jpg,DSC0002.jpg,DSC0003.jpg
```

Note: provided all of the information described above is contained therein, an appropriately structured Esri Shapefile may be delivered instead.

Additional Reference Information

A short report on the survey and coordinate system should be provided, this can be provided in MS Word format. Please include the following:

Project Title:				
Coordinate System:				
Horizontal Units of Measure:				
Vertical Units of Measure:				
Vertical Height:		Ellipsoidal or Orthometric		
Geoid used:				
Date of Survey:				
Responsible Surveyor:		Name, e-mail, telephone number		
Responsible Organization:				
Survey Methods used:		GNSS/Total Station/Spirit Leveling		
Estimated Accuracy:		**X**	**Y**	**Z**