Ground Control for Satellite Remote Sensing

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Motivation

Real-world geospatial data are located with a measuring device; thus, products from different sources, such as imagery and ground measurements will have a relative uncertainty. Common consumer GNSS devices have an absolute uncertainty of ~±3m, while modern satellite imagery may have a pixel size of ≤0.5m. Ground reference data and imagery layers can therefore be misaligned by several pixels, significantly affecting applications such as training of machine learning classifiers.

This article briefly describes methods to align satellite imagery with ground reference or other field data, both for collocation and geolocation.

Equipment and Method

Basic Setup

The conventional method for achieving high-accuracy GNSS measurements is to use differential GNSS (dGNSS). This method uses a static GNSS receiver, known as the base, that is mounted at a single location for the duration of a set of measurements, and a second device, known as the rover, is moved relative to the base station to make measurements.

The base records a single coordinate as its known location at the start of a set of measurements. This value may be manually entered or determined automatically by averaging a set of measurements. If using the averaging technique, this location will have an accuracy of ~±3m relative to the coordinate system of measurement.

The rover is connected to the base station via a radio link (usually) and is moved to record measurements at different locations. During this time, the base is making measurements of its own location at a frequency of the order of 1Hz. Each of these measurements will have its own uncertainty and will differ from the recorded location of the base. The difference between the measured location and the recorded location is a vector. This vector is sent to the rover and the used to correct the rover's measurements. In this way, the error of the rover *relative to the base* is reduced to ~±20mm.

Figure 1 below shows a dGNSS setup. The base is mounted on a tripod designed to be fixed to the ground. The connected pole supporting the receiver head is mounted on a tribrach, which allows the receiver to be levelled with a fine degree of accuracy and mounted exactly over a ground mark such as a survey peg. The rover is mounted on a long pole with a pointed end, allowing exact measurements of ground when held by hand. The pole in Figure 1 has a removable bipod attached, which allows the pole to be mounted vertically at a point in a semi-permanent fashion. While in this case the rover is a ground system it may also be a drone receiver, or any other dGNSS-capable device.

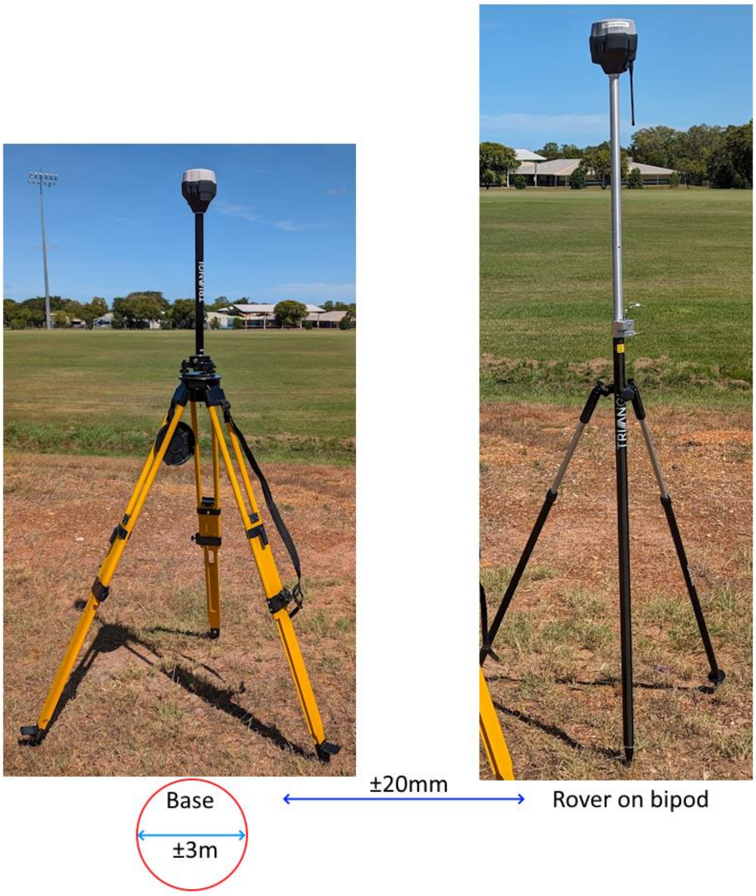

Figure 1 - dGNSS setup and uncertainties.

RTK vs PPK

There are two modes of operation for the base and rover combination, real-time kinematics (RTK) and post-processing kinematics (PPK). Both do the same thing, i.e., provide corrections to enable highly accurate rover measurements or positioning, but differ in their implementation. RTK provides real-time connection between the devices, so that the positions that the rover records are corrected as they are recorded. For PPK, rover measurements are recorded with the usual ±3m error. Corrections are applied during post-processing to improve accuracy. Both methods produce similar results in the final accuracies, the difference is that RTK requires a constant radio connection between the two receivers; PPK does not. This means that if the RTK radio connection is broken, as may happen in the case of large-area drone flights, data may be affected. This does not occur with PPK. In contrast, if dGNSS is being used to provide centimetre-accurate machine control, as in digital agriculture application, PPK will not be appropriate.

Base Location Correction

As the base location has ~±3m error when its location is determined by averaging, data locations from the rover relative to a datum such as MGA is still not known accurately, even if the relative accuracy of measurements is high. To determine an accurate base location there are two basic methods – measurements of a known physical point, or correction services such as AUSPOS (Geoscience Australia, 2024; Janssen & McElroy, 2022). The former is a surveying technique and not likely to be applicable here.

The AUSPOS service takes recorded observations ("static" observations) from the base station and provides an accurate location, to ±20mm under ideal conditions. The input to the service is any common GNSS observation file format such as RINEX. The GNSS base software has an option to record static observations (these are also used for the PPK method), which produces a file which can be exported to RINEX. This file forms the basis of PPK correction, and may also be recorded during RTK measurements, however the file is not required in the case of RTK. The RINEX file is downloaded from the base receiver after the measurement session and submitted to the AUSPOS website. Assuming no errors, a report will be returned which provides an accurate MGA location of the base. This accurate location can be used to correct rover measurements by a bulk shift after preprocessing, or by providing the accurate base location before preprocessing data such as lidar. Note that at least 1 hour, and preferably 2 hours, of static observations are required to produce an accurate base location. With fewer observations errors will be higher, though the errors are noted in the AUSPOS output.

Ground Control

It is not necessary that remote sensing layers such as ground measurements and imagery be accurately geolocated, only that they be collocated. Achieving this requires ground control which is measurable in all layers. To achieve this in remote sensing there are two main types of ground control used – ground control points (GCPs), and natural features (Congalton & Green, 2019).

Figure 2 - UAV ground control point deployed with GNSS receiver. The GNSS receiver is recording static observations to allow high-accuracy geolocation. For satellite remote sensing such a GCP would need to be significantly larger.

GCPs for satellite imagery can be difficult construct and use, as typical satellite resolutions require ground control points that are large enough relative the ground sampling distance of the sensor. However, for high resolution (≤50cm) imagery they may be feasible. GCP's are common in higher-resolution applications such as drone-based remote sensing. Typically, they consist of high-contrast (black vs. white) regions that distinguish the centre of the object. The object is measured with a GNSS receiver to obtain its location relative to the ground reference data. The imagery or ground reference data may then be shifted to align the measured location with its location in imagery layers. Figure 2 shows a deployed UAV ground control point with a GNSS receiver recording static observations to allow accurate geolocation on an established grid.

For satellite imagery, a more typical method is to measure ground features with defined edges which are likely to be visible in the satellite imagery. Infrastructure such as the edges of buildings, roads or light poles are often used, however any feature with a defined edge such a rock outcrop can also be effective. Sharp corners, such as the corner of the building (Figure 3) are helpful as these allow x and y correction vectors to be used.

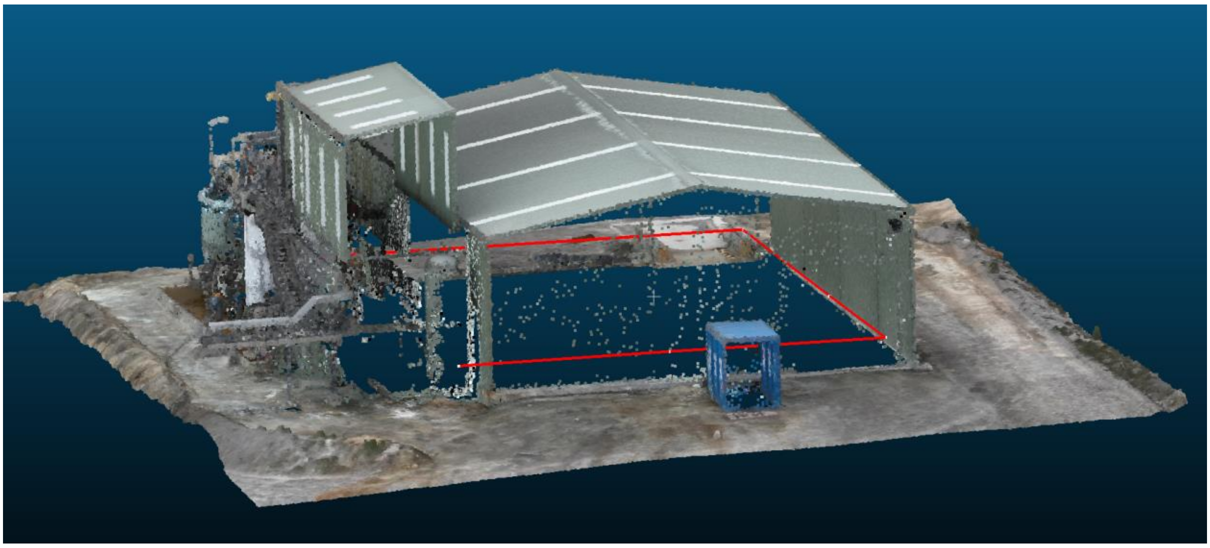

Figure 3 - GNSS recorded line string around a building base compared to lidar records. Clearly, the lidar and GNSS records are not aligned and the lidar data will need to be shifted.

Surfaces such as roads allow for vertical accuracy to me measured. Figure 4 shows a road with a 3D faces. Red lines indicate the road edge; blue lines are bank bottom, pink are bank top, grey is road centreline, and yellow-brown are the 3D faces. For satellite imagery, just the edges of roads can be recorded as line strings.

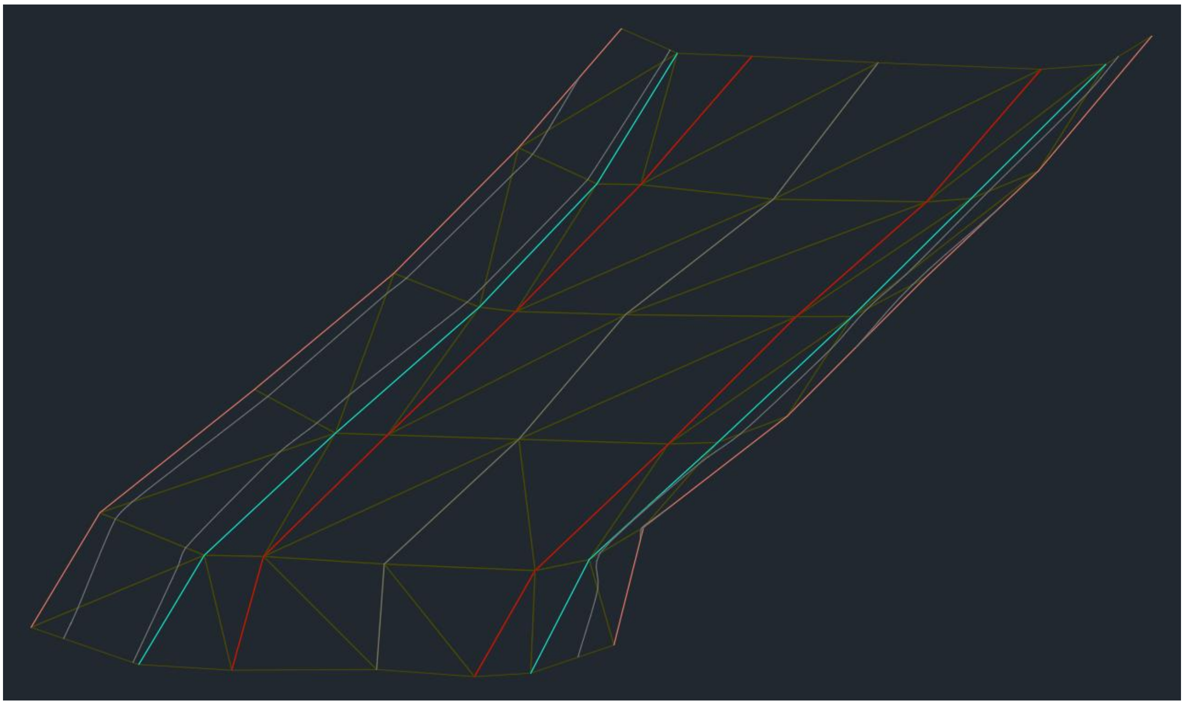

Figure 4 - 3D reconstruction of a section of a road to be used as ground control for a lidar study.

An alternative method is to provide a buffer inside ground reference boundaries to account for any potential misalignment. However, satellite imagery may have higher error than the ±3m of GNSS. The author anecdotally notes that there are locations in Merimbula, NSW, at which the Google satellite imagery is ~30m out from the MGA grid (which, at the time of writing, is identical the WGS84 UTM grid).

Multitemporal GNSS

In many cases it is desirable to collect multiple data sets of the same location over a period of time, e.g., UAV multispectral monitoring of pastoral land. In this case dGNSS can provide high relative accuracy for each consecutive measurement or flight by positioning the base at the same location each time and using the same value for the base location during static observations. In this case, the coordinates of the base may be determined by averaging in the first measurement, with subsequent observations using that same coordinate.

Typical survey practice is to hammer a large wooden peg into the ground, into which is driven a flat head nail, as in Figure 5. The base is mounted directly over this nail and the coordinates of the base manually entered. Each data collection will then be ±20mm accurate, relative to each other. Grid accuracy can be obtained with AUSPOS.

Figure 5 - Survey peg with flathead nail.

Future Directions

Australia has deployed SouthPAN, Australia's Satellite-Based Augmentation System (SBAS). This system provides satellite-broadcast real-time GNSS corrections to any SBAS capable device (Australian Maritime Safety Authority, 2023). Accuracies for these systems are typically 0.1 to 0.5m, depending on location and other factors. Devices such as the Eos Arrow 100 are designed with GIS users in mind and require only one device and no static base, creating the potential for fast and cheap ground reference measurement.

The advantage of dGNSS over SBAS is, and will continue to be, that the lower relative uncertainty (i.e., base to rover) allows for models such as point clouds or orthophotographs to be produced with high geometric accuracy. SBAS technology will not soon replace RTK or PPK (both forms of dGNSS) in UAV data collection, for example. Additionally, the increased accuracy will continue to be useful for ground reference for very high resolution (≤ 0.5m) imagery. However, with more typical ground sampling distances such as 10m for Sentinel-2, or with larger areas of ground reference data, SBAS receivers present may a cheaper and more convenient method of geolocation that is effective to within the required error.

Figure 6 - SBAS receiver stored in a backpack for transport.

References

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Congalton, R. G., & Green, K. (2019). *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices* (Third edition). CRC Press.

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