Capacity Building in Africa: Training the Next Generation of Surveyors in Building High-Accuracy Digital Twins in South Africa

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Abstract

During the Federation Internationale des Geometres (FIG) Annual Meeting 2026 in Cape Town, the Department: Land Reform and Rural Development (DLRRD) will demonstrate its approach to high-resolution 3D mapping. By combining long-dwell DGNSS surveying, Continuously Operating Receiver Stations (CORS) DGNSS, and DGNSS-enabled drones, we have been able to map urban, rural, remote, and indigenous regions with 5 cm absolute accuracy, with a significant increase in efficiency over traditional ground surveying.

The intention of the training is to provide a comprehensive and detailed demonstration of the methodology. For executives and directors, we will focus the first and last sessions on understanding how to be an effective consumer of high-accuracy 3D collection programmes. The intermediate sessions will take the participants through an accelerated collection program, including participating in the collection of a site in the Cape Town area. Participants will perform mission planning, collection planning, collection execution (including ground control surveying in the field), post-processing, quality control, exploitation into GIS/GISc and digital twins, and post-mission documentation, including an out brief to the executive/director participants.

Historically, the maintenance of authoritative geodetic databases is the function of the national geodetic survey organizations, such as the Chief Directorate: National Geo-spatial Information (CD: NGI) in South Africa and their equivalent organizations worldwide. Every authoritative 3D database suffers from a burden of currency and completeness, in which the time between resurvey events defines an epoch during which the previous survey ages sufficiently to be marginally adequate for current needs. Issues of cost, access, and update frequency limit the quality, coverage, and currency of any curated database.

The transition to hybrid surveying using drones provides a unique opportunity in that the drones directly exploit the local and national geodetic DGNSS framework and produce dense, high-resolution, highly accurate 3D imagery. This hybrid surveying approach was pioneered by the Survey of India in the Survey of Villages Abadi and Mapping with Improvised Technology in Village Area) (SVAMITVA) project that successfully mapped 60 million rural land parcels.

South Africa has embraced this model and applied it directly to mapping 836 Indigenous regions that lack detailed property maps. DGNSS-enabled drone surveys extend the precision and accuracy of RSA's DGNSS network (TrigNet) for cadastral mapping of property suitable for its Land Planning Programme (LPP). DLRRD is building a prototype of an off-grid, locally managed, and operated GISc work site built into transportable containers that bring the GISc, communications, and drone infrastructure to the local community.

1.1 Introduction

Since 2024, we have collaborated on an initiative focused on **capacity building in South Africa** focused on training a new generation of surveyors in **high-accuracy digital twin generation**. The core goal is to teach **affordable geospatial information science** and **geospatial knowledge infrastructure** for rural, remote, and indigenous communities in South Africa and other developing nations, utilizing **hybrid surveying techniques** that combine drones with **Differential Global Navigation Satellite System (DGNSS)**. Part of the challenge of this program is the necessity of rigorous training in challenging, remote environments with poor connectivity and extreme weather to ensure the **5-centimeter absolute accuracy** standard is possible, even under these conditions which complies with the CD: NGI cadastral surveying standard of 5 cm circular error at 95% probability (CE95) and 30 cm linear error at 95% probability (LE95. We will address the importance of processes like **self-certification and independent verification and validation (IV&V)** in maintaining accuracy standards through peer review. Examples of successful, high-resolution mapping projects in South Africa are shared, alongside the identification

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of a historic test range in Arizona, USA, as an ideal site for challenging training due to its known accuracy, poor cellular coverage, and harsh conditions, reinforcing the need for **consistent discipline and redundant surveys** for achieving certified 3D control data.

The concept that we're trying to achieve in South Africa, and we think is broadly applicable to perhaps 150 countries in the global south is to teach affordable geospatial information science and geospatial knowledge infrastructure for rural communities. We're going to demonstrate the progress in the last year at DLRRD in high resolution mapping that combines long dwells surveying with DGNSS-enabled drones and allows mapping rural, remote, and indigenous regions with 5cm absolute accuracy with a significant increase in efficiency over traditional ground surveying.

We will identify and solve some outstanding teaching issues, specifically, finding a place where surveying is hard so that in training, we can learn how to deal with circumstances that are not desirable. Training cannot occur in a capital or in a major city such as Cape Town but should be performed in a remote area where long baseline differential GNSS is needed, where VRS and cell coverage are poor, and where weather is extreme. Simultaneously we need a place where the answer is known so we can self-qualify the results. Additionally, we'll talk about self-certification internally to an organization and IV&V externally and how to know the solutions are correct. Every country has a challenge with authoritative databases that struggle with both currency and completeness, and we all struggle with issues of cost, access and update frequency which limit the quality, coverage and currency of any curated database.

1.2 Methodology

The proposed solution follows in the line of the work of the Surveyor of India with the SVAMITVA program and extends to look at using hybrid surveying using drones combined with DGNSS surveying and control with modern drones. Additionally, we are working on a scheme where this can be made highly portable, and deployable in an **off-grid locally managed environment (UMGCINI)**. The desired end state being that we believe that local and indigenous communities can build and maintain their own geospatial knowledge science system environments and curate those into the future.

Beginning with methodology which is somewhat tutorial but appropriate in order to maintain 5cm accuracy in drone surveying where you have to do everything right all of the time which is challenging but not overly difficult with suitable training. Core elements include project definition and requirement specification, careful mission planning, exquisite collection planning, and ground control point surveying, so we can do the self-certification and the verification post collection, and include processing peer review, quality control, initial self-certification, and independent verification and validation. Affordable external peer review is challenging but can be enabled with effective integration of the data into databases and cloud infrastructure, ideally using **open-source software** to minimize cost and maximize interoperability. Post mission documentation is always important, as a survey is only as good as its documentation.

1.3 Recommended Standard Operating Procedure

RSA's DLRRD drone program has dramatically improved the geodetic accuracy of its collection program by fully exploiting the DGNSS capabilities of its drones in a carefully managed "standard operating procedure" that emphasizes data redundancy and overlap to ensure that a single collection meets CD: NGI requirements regardless of the inevitable variability due to weather and topography.

1.3.1 Project definition and requirements specification

As with any field collection, requirements definition and up-front error management are critical to enable collection requirements that are marginally larger than the performance requirements of multiple components.

1.3.2 Mission planning

Mission planning, at the limit of error propagation, requires a conservative approach to maximize the density and overlap of the collection lines to ensure that variation due to weather and topography does not degrade the accuracy of the collection.

1.3.3 Collection planning, including ground control point surveying

Designing and implementing the collection planning, including the deployment of multiple DGNSS base stations, long dwell PPP DGNSS collection, and deployment and surveying of photo recognizable ground control points.

1.3.4 Post-collection processing and survey peer review

The production of the survey, GIS, and digital twin products, including customer-facing products that demonstrate the product quality and accuracy.

Rigorous peer review of all survey products while the collection team is in the field.

1.3.5 Quality control and self-certification

Quality assurance and quality control of the products are part of the self-certification process to ensure that the Geospatial Knowledge Infrastructure (GKI) products are self-consistent, self-documenting, and self-certifying.

1.3.6 Independent verification and validation (external peer review)

We recommend the employment of an independent verification and validation (IV&V) team. This process stresses the documentation of the data to ensure that external users can independently validate the precision, accuracy, currency, and completeness of the data.

External evaluation of compliance with OGC's FAIR (findable, accessible, interoperable, and reusable) standards to ensure that non-technical consumers can utilize the data.

1.3.7 Integration into GIS and GISc databases, including cloud deployment and use of open-source software wherever possible.

a. Creation of internal and external databases.

b. Creation of digital twins for mobile and edge exploitation.

c. Maximal usage of open-source software.

d. Identification of commercial-only software solutions.

1.3.8 Post-mission documentation

a. Validation of metadata and documentation.

b. After action reports covering compliance and non-compliance of the “as collected” archive.

1.4 Examples

We provide a few examples from the work in South Africa over the last year, as the drone program has developed its capability with more than 50 surveyors qualified to fly drones. An example area in **Bloemfontein** (Figure 1) with 76 control points illustrates a high-resolution, high-accuracy survey that is compliant with the national standards in the horizontal and just marginally outside of vertical standards including all of the data at 33 cm LE95. If we exclude the lines that were too fast due to wind gusts, we very quickly have the Z values that fall into within the 30 cm LE95 specification.

Figure 1. Example survey in Bloemfontein, South Africa.

A second example in the far northeast of South Africa in Matiyane (Figure 2) includes a 10 km high resolution mesh collection with 8 cm C95 and 33 cm LE95, again just marginally outside the desired standard.

A third example in the **Karoo** (Figure 3) in the rural west of South Africa has a 19 cm CE95 and a 12 cm LE95 yielding a **near digital twin** produced from that survey. Note there is an example of some of the imperfections in these data sets, the steeple is slightly asymmetric.

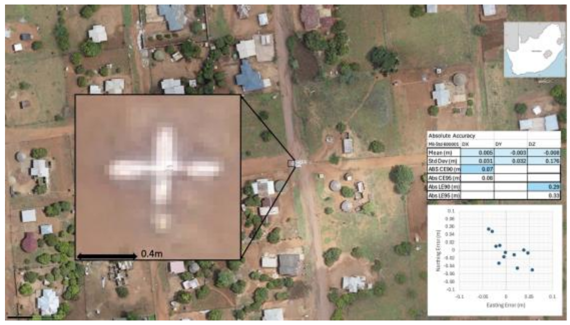

Figure 2. Drone survey in Matiyane South Africa.

Figure 3. Example survey in Victoria West, South Africa.

1.5 Observations

From a teaching point of view, the challenge is how do you teach people to know that the methodology works at scale in a challenging environment. He first problem is access to truth data. The second issue is access to a site that is challenging without being unfair. We found a similar example in the United States as a teaching site which is someplace that's been used for decades where we can embed teachers in a university model and evaluators to ensure consistency and fairness. This site **southwestern Arizona** near the Mexican border in the Indigenous nation of the Tohono O’odham which has poor cell coverage and correspondingly poor VRS DGNSS coverage, indicating that it's an ideal site to challenge equipment and operators. We surveyed this site earlier in October and even though it was fall, we did have to deal with **temperatures over 102°**, surface temperatures about 115° and we had significant equipment failures, as you'd expect and as you'd want from a training program. The Casa Grande Photogrammetric Test Range is a historic test range, designed as a part in 100,000 accurate range in the 1960s. As built, it exceeded those specifications with an accuracy of about a part in a 300,000 for actual photogrammetric accuracy. As we surveyed earlier this month, we were able to demonstrate a centimeter in 20 km, which is about a part in 200,000 exceeding the initial specification quite nicely. The site 16 mi x 16 mi and it has **116 remaining large 60-foot concrete crosses** which make it ideal for drone, airborne, and satellite calibration (Figures 4 and 5).

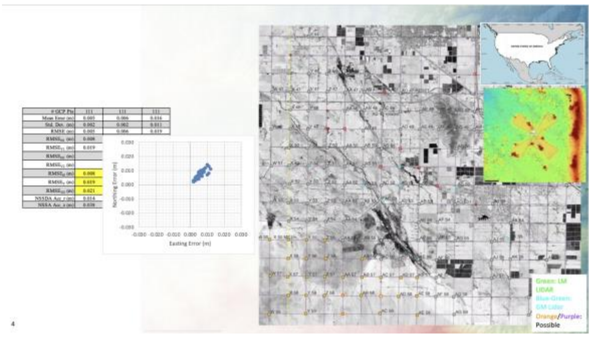

Figure 4. Casa Grande Photogrammetric Test Range LIDAR survey.

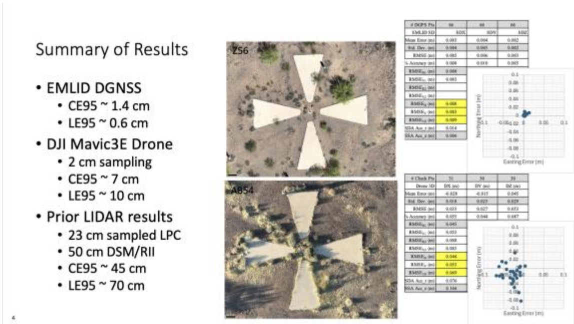

Figure 5. Mavic3E Drone Survey and Emlid DGNSS survey results at Casa Grande, Az.

Between the examples in South Africa and the United States, we are establishing a set of best practices, consistent with ASPRS 2024 recommendations, suitable for DGNSS and DGNSS-enabled drone surveying under less-than-ideal circumstances. With practice and discipline, we are able to demonstrate data suitable for self-certification, independent verification and validation and appropriate for national class cadastral data using drones that are consistent with traditional national geodetic products.

From a tutorial perspective, we have tried to avoid “cherry picking” the best data and illustrating real world scenarios, which miss the survey objective by a small amount, and have results that come out slightly worse than intended. What we've been doing in South Africa and in the United States, from a teaching point of view, is to use independent reviewers to independently source control data and do independent verification and validation as a way of establishing both rigor and independence of the survey data.

1.6 Lessons Learned

Lessons learned to date include:

a. Survey **photo-recognizable 3D points,** which sounds obvious, but it's surprising how often surveys only require height testing).

b. We advocate the use of **long dwell DGNSS and PPP processing** to establish control on the assumption that you are both remote from base stations (more than 50 km) and that you're in a communications challenged environment.

Ideally, if you can do that, coupled to an existing reference network like TRIGNET, then we have the ability to compare and validate over epochs and over between different survey teams.

c. We believe in **redundant surveys**: two is good, three and four are better.

d. Consistent with ASPRS2024 standards, we recommend 30 ground control points per site or AOI with a desired survey accuracy 3 times better than the objective survey under validation.

e. Assume that the reference networks and cell service are going to be poor. Bring **high-powered VHF radios** and or satellite-based correction services, to be capable of operating on the assumption that the local network is unavailable.

f. Finally, **equipment will fail**. In our case, our smart controllers were consistently taken out by overheating, and we ended up having to shield them and wrap them in MLI (an emergency blanket) to keep them cool. Being prepared to re-engineer in the field is not a bad assumption.

g. One of the “value-added” benefits of this methodology is the ability to self-certify and validate a survey while in the field and minimized the opportunity for a second survey. However, in practice, remote areas surveys tend to be multiple survey events, regardless of intention and discipline.

h. We recommend over-scheduling by about 30% and simultaneously assume that you'll never return to the site and so take the time that you need to do the work carefully and repetitively while you're there.

1.7 Conclusion

The desired end state is to consistently survey teams capable of providing qualified and certified 3D control data that is tied directly to dense DGNSS survey networks and GCP validation points to yield high accuracy 3D data in remote areas with the caveat that one has to pay careful attention to the standard operating procedures.

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