Working toward an optimized PPK workflow solution for accurate aerial photogrammetry surveys to support dynamic construction worksites

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Abstract:

With the onset of large-scale economic and infrastructure development projects in PNG such as the Papua LNG Project, Wafi-Golpu Copper/Gold Project and the Connect PNG Program 2020-2040 amongst others, AEC companies are expected to increase productivity and as such require a sizeable workforce. This includes experienced professional geospatial consultants and companies with specialist technical skills in surveying, remote sensing, photogrammetry, GIS and mapping.

Commencing 2024, there will be an estimated eight years of continuous engineering and construction work from the Papua LNG Project in the Gulf and Central Provinces then followed by the P’nyang Gas Project in the Western Province. The AEC industry is undergoing a digital transformation and would therefore require technical geospatial information rapidly that are comprehensive, accurate and up-to-date using innovative workflows for seamless integration with BIM design information for construction.

Accordingly, a resilient workflow integrating a number of modern geospatial technologies is required that can adapt to an evolving construction work environment in order to continually deliver quality results to the client economically. It is therefore feasible to migrate toward the PPK workflow solution for aerial photogrammetry surveying because it ensures rapid capture and delivery with minimal field time, has exceptionally high survey-grade accuracies as demonstrated by a test case here and, in doing so, maximizes cost efficiency.

Keywords:

Aerial Photogrammetry, Post-Processing Kinematic, Real-Time Kinematic

1.0 Introduction:

Advances in technology have made the RTK-enabled aerial drone an affordable tool for construction worksites as they enable faster, safer, more affordable and higher-resolution surveying, without sacrificing on accuracy. When integrating an optimized PPK workflow solution that incorporates photogrammetry geoprocessing and also GIS modeling, it ensures the most efficient, reliable and accurate results possible. PPK aerial photogrammetry would be most appropriate for medium-sized project areas (1-5 km^2 or 100-500 hectares) and/or frequent resurveys of dynamic and busy construction worksites with quicker turnaround times. It is also especially important for hard-to-reach assets, inaccessible or hazardous areas such as flood zones or steep terrain where operations downtime needs to be kept to the absolute minimum.

Strident7 Mapping was engaged by ALSL in October 2022 to carry out an aerial photogrammetry survey of the Bunu Water Supply Project in the Central Province. After preparation and mission planning, the aerial photogrammetry survey was undertaken for topographic mapping using a small multirotor drone platform. During field operations, the RTK method was implemented including GCPs used as control points to maintain high position and height accuracies. The PPK method was conducted on a test case in Mission 3 after field operations and involved transferring corrected positional fix and time synchronization data from the drone D-RTK2 mobile base placed on a known survey mark in the local project area to improve positioning of the geotagged drone captured image data.

The corrected drone captured data were then processed using the photogrammetry algorithm and also incorporating a GCP as a control point. The deliverables generated included orthomosaic imagery, point clouds, DEM/DSM and contours. These deliverables were then further geoprocessed in GIS to add value by vectorizing the orthomosaic imagery through spectral analysis and then modeling potential high risk to flooding using cartographic techniques. These geospatial information can then be used to help with AEC designs in order to build digital twins of the infrastructure or the landscape.

2.0 Objective:

The goal is to procure, process and provide quality geospatial information quickly and cost efficiently for dynamic construction worksites. Therefore, the primary objective here is to demonstrate the viability and validity of migrating to an optimized and seamless PPK workflow solution for aerial photogrammetry surveys in PNG conditions using data from a test case. This involves leveraging geospatial technologies and automation, including data processing, geomodeling and mapping software, to provide quality and value-added deliverables.

3.0 Project Area:

The Bunu Water Supply Project is located about 27 km northwest of Port Moresby city, about 8 km north of the PNG LNG Processing Plant and about 7 km inland from the coastal villages of Papa/Lealea in the Central Province. The project site comprises Portions 647 and 648 with a total area of about 353 hectares and has undulating hills with grassland and scattered trees including low-lying areas subjected to constant flooding. Portion 647 is located predominantly in a flood zone surrounded by the Laloki and Bunu Rivers including Lake Bunu while Portion 648 is located on relatively high ground with access roads. There is a small water treatment plant on site operated by Water PNG Limited.

4.0 Overview of geospatial technologies used in this project

The following geospatial technologies and techniques have been used to develop and optimize the PPK workflow solution that rapidly captures and processes field data accurately within the test case of Mission 3 to generate quality and value-added topographic information.

4.1 UAV

UAVs or aerial survey drones have a role to play in the surveying and mapping business as they provide an effective data capture tool, collecting accurate information safely and efficiently. The aerial survey was carried out using the multirotor DJI Phantom 4 RTK drone platform with a 20-megapixel (5472 x 3648 resolution) photogrammetric camera payload, a remote controller and a D-RTK2 mobile base station with satellite positioning capability. The RGB camera with 8.8 mm focal length is a precise imaging system that is synchronized with the RTK module and has a mechanical shutter to eliminate image distortions amongst others. The on-board GNSS receiver provided accurate positioning and the IMU measured the aircraft’s trajectory (yaw, pitch and roll) during the orchestrated flight.

4.2 GNSS

GNSS comprises a constellation of satellites (GPS, GLONASS, Galileo, Beidou and others) providing signals from space that transmit positioning and timing data for better signal reception and redundancy. The ground-based receivers use the data correlated from multiple satellites to precisely determine their location. The terrestrial surveys provided GNSS survey control that were used as GCPs to optimize the level of accuracy for the aerial drone survey. The two common methods of GPS correction technologies are RTK and PPK that have been used as the default form of control with minimum GCPs for aerial photogrammetry surveys.

4.3 RTK

The DJI Phantom 4 RTK survey drone carries an on-board GNSS RTK receiver that gathers data from satellites and a stationary ground-based station to accurately correct image positons in real time during flight operations. Planned missions were uploaded to the remote controller to enable capturing high-resolution images with precise geotagging for converting the aerial image data into accurate point clouds. This drone stores the satellite observation data for PPK processing and also has the capability to capture field data through PPK without the real-time connections. <Ref. X> Satellite data is error prone due to atmospheric delays amongst others and providing low positioning accuracy when the RTK link is interrupted as was the case here.

4.4 PPK

The RTK technology requires uninterrupted communications from the drone D-RTK2 mobile base station to the on-board aerial drone GNSS receiver. Once the RTK link is interrupted then the captured photo images loses positional accuracies. PPK has become the standard for UAVs and manned aircrafts capturing accurate data for photogrammetry or LiDAR and provides backup when the RTK link drops out unexpectedly during field operations. PPK processing of the GNSS positioning and time synchronization data from the aerial drone rover and base after flight operations was carried out with the KlauPPK Geomatics software.

4.5 GCP

GCPs are surveyed marks on the ground with known coordinates strategically placed around the project area which shows up in the captured photo images as identifiable coded markers. These images are geotagged by the drone's on-board navigation system and then the aerial drone data and GCP location can be compared and realigned for accurate positioning. One GCP per mission was used to render the model correctly and this became feasible when used especially with PPK using a base station to tie down the drone captured data as demonstrated with the test case discussed in this paper.

4.6 SfM Photogrammetry

SfM photogrammetry is a remote sensing technique using captured aerial drone data where multiple overlapping photographs are stitched together with common feature tie-points to create a 3D set of points corresponding to the surface features with XYZ coordinates called a point cloud with associated RGB. Multiple photos captured from a variety of perspectives were processed with the Agisoft Metashape photogrammetry algorithm to construct the topographic "structure" of the scene within the subject area from the "motion" of the cameras. The point clouds in turn helped generated the DEM/DSM, contours and the orthomosaics.

4.7 GIS

The ESRI ArcGIS desktop is a machine learning software application used to synthesize geospatial information for analysis, modeling and mapping. The photogrammetry data output of point clouds, contours, DEM/DSM and orthomosaics were geoprocessed and then geomodeled to add value to the final product.

4.8 Google Earth

Initial planning was done in Google Earth to prepare for optimal flight operations during the aerial field survey. This involved delineating the area of interest and determining multiple missions including possible locations of the GCPs with geodetic coordinates. These information were then uploaded into the drone remote controller for flight planning and operations.

5.0 Optimizing an integrated workflow for PPK Aerial Photogrammetry

This optimized workflow integrates the aerial drone, GNSS, RTK, GCP, PPK, SfM photogrammetry, GIS and Google Earth to undertake especially medium-sized project areas with increased spatial and spectral accuracy including quicker turnaround times temporally (refer to Figure 1).

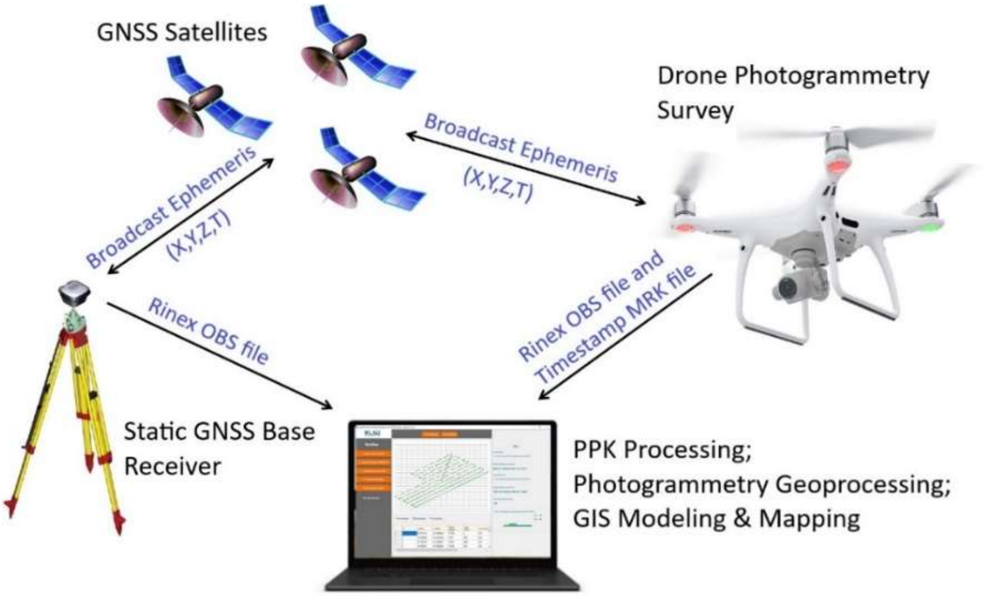


Figure 1: Optimized PPK workflow solution for rapid, accurate and cost efficient aerial photogrammetry surveying, post-processing, geomodeling and mapping operations. Field time and costs are minimized due to a streamlined workflow with fewer manpower and equipment while covering large areas quickly to deliver quality data with survey-grade "sub-centimetre" level accuracy and resolution.

5.1 Preparation and mission planning for field operations using Google Earth

Cadastral boundaries of the project area were reproduced from a survey CAT plan (49/3097) and converted to KML format in Google Earth (refer to Figure 2). The project area was divided up into 25 missions with each covering an area of about 20 hectares and that could be captured within 20 minutes by the aerial drone at 100 metre altitude consistent with CASA PNG's statutory regulations (Part 102) and in order to maintain acceptable survey-grade accuracies.

The KML files of the project missions were uploaded into the remote controller ready for flight operations planning using the 2D photogrammetry data capture method. These same missions can be flown again using the same flight parameters to monitor progress against the baseline data and measure level of change. The DJI Phantom 4 RTK drone uses the WGS84 datum with geodetic coordinates in latitude, longitude and ellipsoidal height format as used by the GNSS.

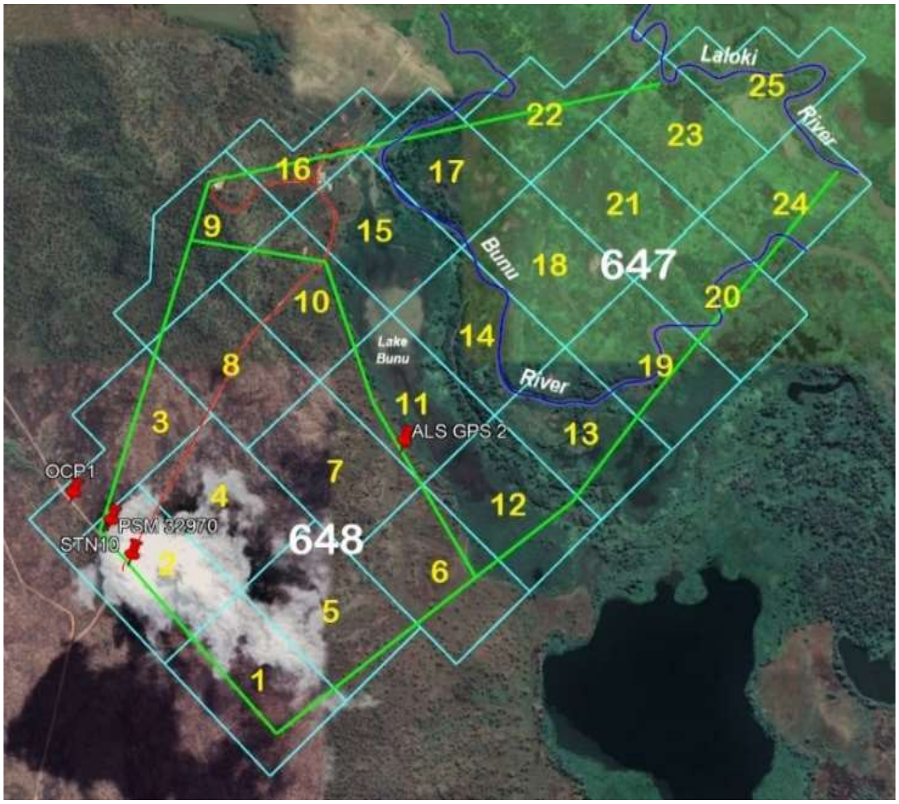


Figure 2: Project area showing the planned 25 missions using Google Earth for drone field operations with the GNSS survey control stations (red-pin points), cadastral boundaries (green polylines), and missions (cyan polygons). Mission 3 with PSM 32970 (base station) and OCP1 (check point) were selected for the sample subset to test data validity and accuracy when comparing between the RTK and PPK methods.

5.2 Aerial Survey using the DJI Phantom 4 RTK drone including GCPs

When on site, pre-flight checks were carried out including calibrating the drone compass whenever prompted and then Mission 3 was flown on 17 October 2022 between the times of 0945 and 1015 on a bright sunny morning with little wind. The D-RTK2 mobile station was set up at a base location (PSM 32970) with good visibility to the sky for clear line-of-sight to the GNSS satellites and RTK drone at all times. On the remote controller, selected a mission (Bunu3.kml) and activated the 2D photogrammetry capture method with photo overlaps of 80 % (forward) and 70 % (side). The drone captured 336 photo images that were saved on a 64 GB micro SD card and covering an area of about 47 hectares for the model because of overlaps. The GNSS control, cadastral boundary and including the access roads and GCPs were surveyed and coordinated by ALSL with Total Stations and static GNSS receivers while the rest of the project area was captured through aerial drone photogrammetry.

With a Wi-Fi connection to the 4G signal coverage, the drone was flown on autopilot with a 20-megapixel camera lens that was nadir-aligned delivering a high resolution orthomosaic of 5 cm per pixel from 100 m altitude above ground level. RTK relies on GNSS positioning and a stable radio link between the ground base station and a GPS antenna including the IMU on-board the aerial drone or rover. <Ref. IX> There were instances during flight operations where communication between base and drone rover were interrupted with radio link outages and/or GNSS signal blocks resulting in loss of RTK correction data and a lower percentage of accurate camera position and height (refer to Figure 3). <Ref. I>

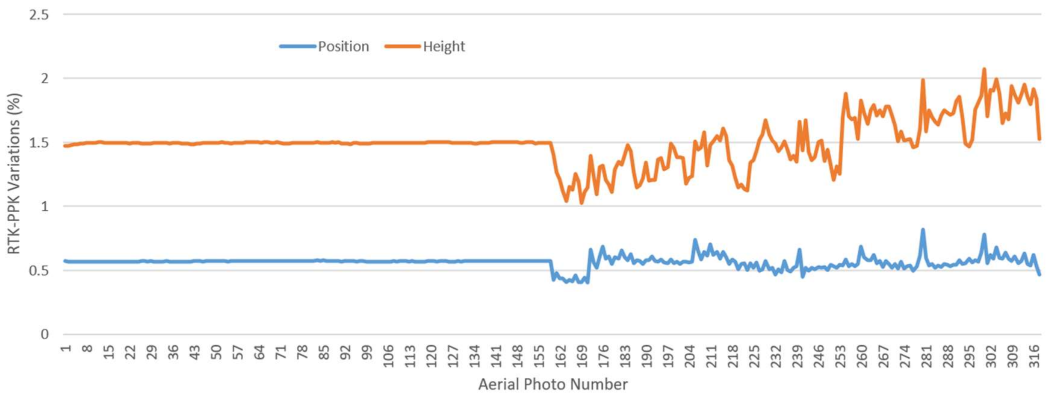
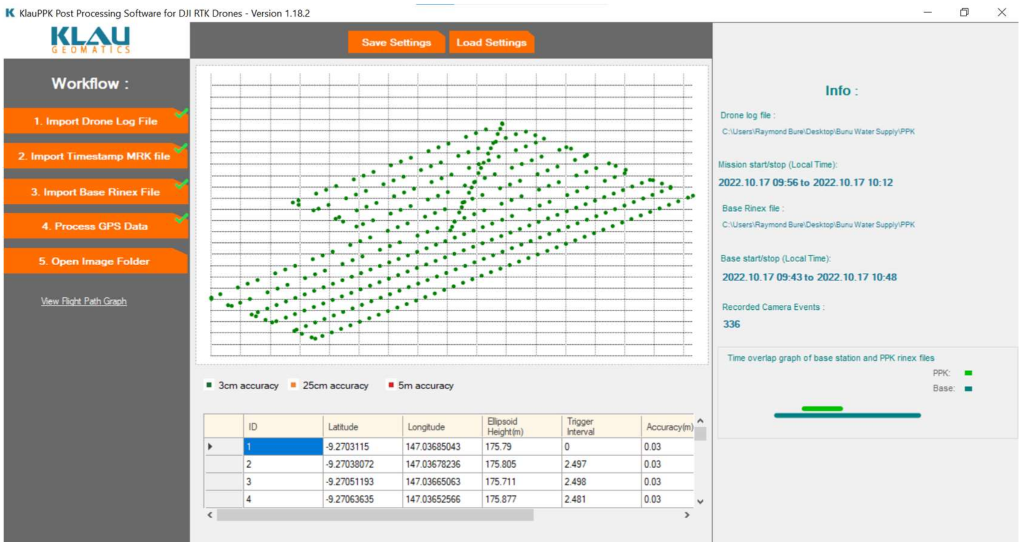


Figure 3: Drone trajectory for Mission 3 displaying variations in camera position and height based on value differences between RTK and PPK over 318 photos and normalized as a percentage for illustration purposes. The drone trajectory was steady in the early part of the mission (photos 1 - 159) but then became relatively "turbulent" for the rest of the mission due to signal interruptions in real time. This caused inconsistencies in especially the latter part of the captured RTK data during the 20-minute flight increasing uncertainty and lowering accuracies. Without PPK as demonstrated in Figure 7, the mission would have had to be flown again.

5.3 PPK processing of captured RTK data with KlauPPK Geomatics

The KlauPPK post-processing software applies the most rigorous processing algorithm to the captured RTK drone data (refer to Figure 4). It produced results with no data loss or initialization loss from RTK radio link limitations. All drone captured data were processed with similar algorithms to RTK running forwards and backwards throughout the dataset. PPK is a more robust solution than RTK, ensuring complete data from both the D-RTK2 base and rover including its trajectory, processed forward and backward repeatedly. Satellite positioning and timing data from both the base receiver and the aerial drone were post-processed together with the PPK method to achieve improved positional and height accuracies for all drone-captured photo centres to within acceptable survey standards.



Drone log file :
C:\Users\Raymond Bure\Desktop\Bunu Water Supply\PPK

Mission start/stop (Local Time):
2022.10.17 09:56 to 2022.10.17 10:12

Base Rinex file :
C:\Users\Raymond Bure\Desktop\Bunu Water Supply\PPK

Base start/stop (Local Time):
2022.10.17 09:43 to 2022.10.17 10:48

Recorded Camera Events :
336

	ID	Latitude	Longitude	Ellipsoid Height(m)	Trigger Interval	Accuracy(m)
▸	1	-9.2703115	147.03685043	175.79	0	0.03
	2	-9.27038072	147.03678236	175.805	2.497	0.03
	3	-9.27051193	147.03665063	175.711	2.498	0.03
	4	-9.27063635	147.03652566	175.877	2.481	0.03

Figure 4: A screenshot of the KlauPPK Geomatics application and data processing of the Mission 3 sample data with the points representing the drone image photo centres. The timing overlap between the Base (dark green bar) and the PPK Drone (light green bar) must be at least 20 minutes or more at the start and end of field operations for a good positional fix which in this case is within 3 cm (green dots/circles) as also partly shown on the right side of the table under the "Accuracy" column.

The raw unencrypted ephemeris data from the D-RTK2 base station was exported using the DJI Assistant 2 application. The protocol data type of the D-RTK2 base station is RTCM format which was converted to the Rinex format. Conducted post-processing with the KlauPPK post-processing software application specifically for DJI RTK drone data. The Rinex.OBS and Timestamp.MRK files comprising the GNSS positioning and timing data including trajectory data were processed forwards and backwards continuously with the GNSS observation data from the base Rinex.19o file to accurately correct the positions of the photo centres. The corrected photo centre coordinates were written into the EXIF metadata maintaining the WGS84 geodetic coordinates in latitude, longitude and ellipsoidal height format.

For the test case in Mission 3, the drone D-RTK2 mobile base was placed on PSM 32970, a known GNSS survey control mark (refer to Table 1), for over an hour with static GNSS observations to improve positioning and increase accuracy for PPK processing. The GCP of OCP1 was used as the check point for the Mission 3 geoprocessing. The fixed height of the antenna was 1.801 metres including 0.1419 metres to the phase centre and this was added to the ellipsoidal height of PSM 32970 and together with the latitude and longitude were inserted into the D-RTK2 mobile base for PPK drone surveying to take place.

Station	Easting	Northing	RL	Latitude	Longitude	Ellipsoidal Height
PSM 32970	503651.152	8974833.518	4.860	-9.274192	147.033244	74.974
OCP1	503513.124	8974930.466	6.016	-9.273315	147.031987	75.651

Table 1: PNG94/PNGMG94/PNG08 coordinates with PSM 32970 used as the base station for PPK and OCP1 used as a check point to pin down the aerial photogrammetry data for geoprocessing in Agisoft Metashape.

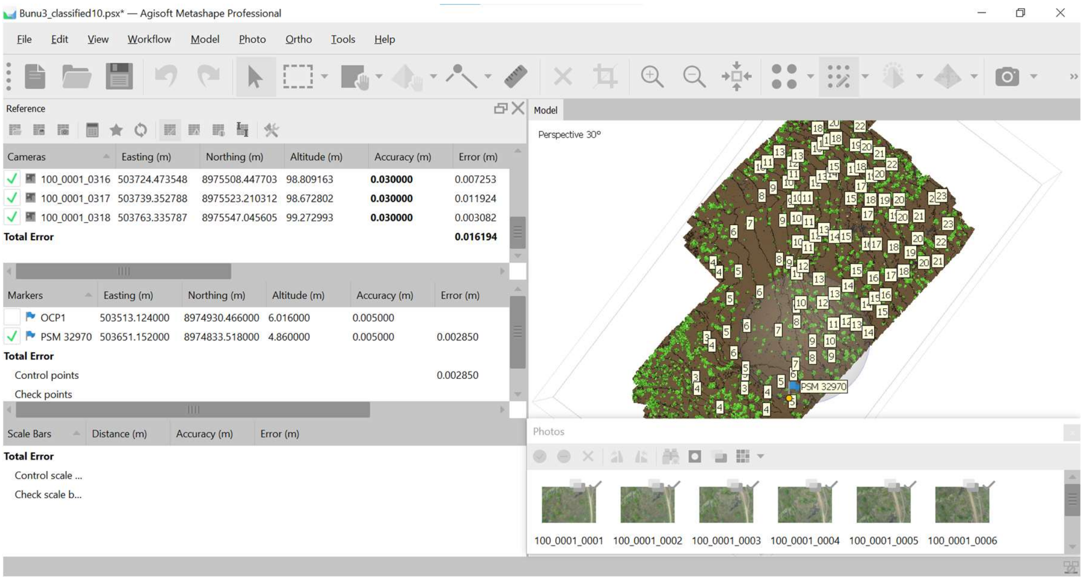
5.4 SfM Photogrammetric geoprocessing with Agisoft Metashape

Aerial photogrammetry is a revolutionary technique that synergizes the power of drones and high-definition cameras to capture sharp, precise images. Its crucial stages involve capture of aerial imagery, image georeferencing, processing of images, generation of models, analysis and measurement. SfM photogrammetry is when corresponding features called "tie-points" are automatically identified from multiple overlapping photos to calculate the relative locations of the cameras to reconstruct a low density "sparse point cloud". <Ref. VI>

A high density "dense point cloud" was then generated based on the filtered and optimized locations of the sparse points and the cameras. The GCP (PSM 32970) with PNGMG94/PNG08 coordinates was added to georeference and tie down the point cloud model that was transformed into DEM/DSM and orthomosaic outputs using a 7-parameter transformation process with one scale parameter, three translation parameters and three rotation parameters. This transformation was linear and rigid and yielded a point-cloud suited for topographic mapping applications.

The captured photo images with embedded coordinates that were cross-corrected against the base were aligned to create a sparse point cloud. The corrected geodetic coordinates in WGS84 latitude, longitude and ellipsoidal height format were written onto the photo image metadata of EXIF with KlauPPK Geomatics and then were all geoprocessed in Agisoft Metashape. The geodetic coordinates were then transformed to the PNGMG94 UTM Zone 55 and PNG08 datum ready for geoprocessing. <Ref. XI>

Registered the GCP (PSM 32970) with its corresponding point (one square-metre red/white coded marker) on the photos and then optimized camera alignment and position to generate a filtered dense point cloud. Conducted classification of the point cloud to categorize into a number of layers. Created DEM which was constrained to the classified ground and road layers to generate contours (refer to Figure 5). From the dense point cloud, the mesh, texture and DEM were built to generate the orthomosaic imagery of Mission 3. <Ref. XII> All drone captured PPK corrected photos were then geoprocessed and stitched together to generate point clouds, DEM/DSM, contours and orthomosaic imagery.



Cameras	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)	Error (m)
✓ 100_0001_0316	503724.473548	8975508.447703	98.809163	**0.030000**	0.007253
✓ 100_0001_0317	503739.352788	8975523.210312	98.672802	**0.030000**	0.011924
✓ 100_0001_0318	503763.335787	8975547.045605	99.272993	**0.030000**	0.003082
Total Error					**0.016194**

Markers	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)	Error (m)
☐ OCP1	503513.124000	8974930.466000	6.016000	0.005000	
✓ PSM 32970	503651.152000	8974833.518000	4.860000	0.005000	0.002850
Total Error					
Control points					0.002850
Check points					

Scale Bars	Distance (m)	Accuracy (m)	Error (m)
Total Error			
Control scale ...			
Check scale b...			

Figure 5: A screenshot of the Agisoft Metashape application showing layer classification of the point cloud model, contours and GCP (PSM 32970) for Mission 3 using the PPK corrected data. The coordinates of all 318 photo centres have been projected to the PNGMG94 and PNG08 datum for processing to generate geospatial deliverables of point clouds, DEM/DSM, contours and orthomosaic.

5.5 Geomodeling to add value using ESRI ArcGIS to help build digital twins

All features captured through remote sensing has its own chemical composition and therefore its own spectral signature. This spectral signature plots all the variations of the electromagnetic radiation as a function of wavelengths. The captured aerial drone photogrammetry data is, however, limited to the visible bands of red (0.64 – 0.67 µm), green (0.53 – 0.59 µm) and blue (0.45 – 0.51 µm) although there is a separate multispectral sensor with capabilities to capture a number of invisible bands. Because of RGB from the aerial photogrammetry imagery, spectral analysis was performed through supervised classification using ESRI ArcGIS where generic raster classes were created and then vectorized into two general map layers of exposed ground surface including roads and vegetation comprising grass and trees. <Ref. VII>

To add value to the final deliverables, a what-if scenario of possible flash flooding events were geomodeled to determine which areas shall be heavily impacted. The three visible bands had their spectral values stretched along a colour ramp and were resampled to create false colour combinations to help identify particular areas of possible water presence on the ground when correlated with large clusters of vegetation which corresponded to brighter shades. Generated slope from the DTM to delineate drainage patterns and using all data including proximity to roads geomodelled potential risks to flooding with cartographic techniques (refer to Figure 6). The derived geospatial information adds value and knowledge to the captured aerial photogrammetry data and would enable building a consolidated and resilient section of the road infrastructure as identified within the potential impact flood zone.

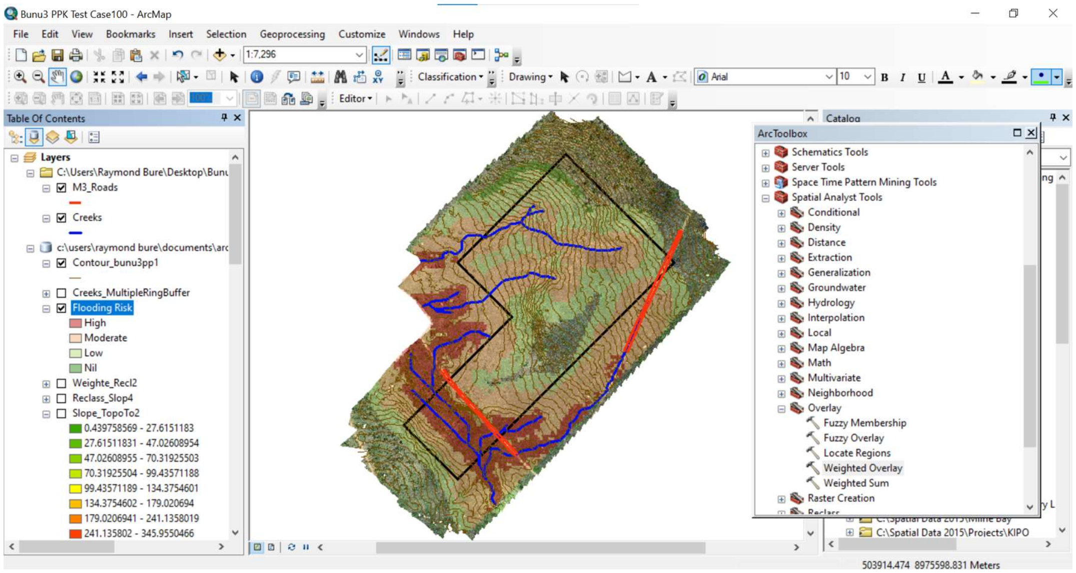


Figure 6: A screenshot of the ESRI ArcGIS application showing geomodeling of potential risks to flooding in especially low-lying areas and adding value to the deliverables. These information can be used by the AEC companies to help with design and construction of a resilient road infrastructure that can withstand flooding hazards and avoid eroding the road surface as well as costly maintenance work and/or reconstruction. Note that the black polygon is the 20-hectare drone flight mission area (or area-of-interest) and because of photo overlaps doubled the size of the captured model beyond the mission area totalling about 47 hectares.

The final deliverable was the topographic map comprising information such as orthomosaic base information (roads, vegetation and other salient features), contours and potential flood-risk areas. Accurate aerial 2D and 3D photogrammetry capture of natural features and built infrastructure provides the GIS information that enables informed BIM engineering design and then together providing the building blocks to constructing a digital twin. <Ref. IV>

6.0 Analyzing and validating accuracy results of PPK Aerial Photogrammetry

According to specifications in the user manual, the DJI Phantom 4 RTK drone has a 1 cm RTK horizontal positioning accuracy and 1.5 cm RTK vertical positioning accuracy. Furthermore, it has an absolute accuracy of 5 cm for photogrammetry models from an altitude of 100 m with a resolution of 2.7 cm GSD.

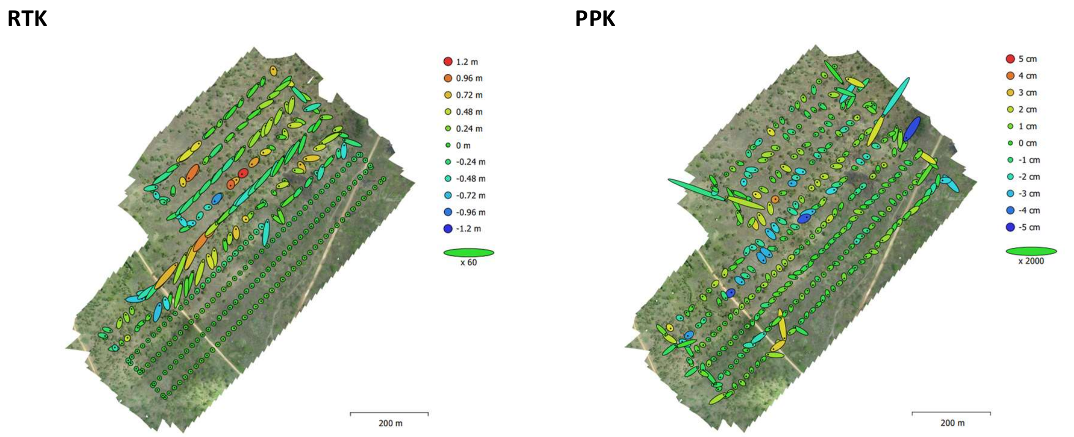
Furthermore for validation, the drone D-RTK2 base station was calibrated by setting up over the ALS Base Station (ALSL Office at Erima) with known coordinates for over 3 hours to achieve centimetre level accuracies. The D-RTK2 base station was used as a static dual-frequency receiver in a standalone mode to log raw satellite observation data from both the GPS and GLONASS satellite systems at a 30-second epoch. Post processing of the raw observation data was independently facilitated by Dr. Richard Stanaway using the online CSRS-PPP and the accuracy achieved in position was 4 cm and 7 cm for height.

For Mission 3, the drone D-RTK2 base station was set up over PSM 32970 which was used as the control point and OCP1 as the check point for geoprocessing of both the RTK and PPK data where there was more improvement in positioning and height for the PPK error estimates (refer to Table 2). <Ref. V>

GCP	Method	X Error (cm)	Y Error (cm)	Z Error (cm)	XY Error (cm)	Total Error (cm)
PSM 32970	RTK	79.98	152.38	313.34	172.10	357.49
	PPK	0.21	0.15	0.12	0.26	0.29

Table 2: Control point RMSE showing error estimates in position and height of PSM 32970 for Mission 3 when comparing between RTK and PPK. The error estimates for PPK in this test case suggests that only one GCP can be used to capture field data through PPK Aerial Photogrammetry. This enables minimal field time while maintaining survey-grade "sub-centimetre" accuracies for quality deliverables and maximizing cost efficiency.

The accuracies from the aerial photogrammetry survey of the project area, were controlled by RTK and GCPs during field operations. When comparing the results between the RTK and PPK methods using the test case sample data from Mission 3 using the same base station (PSM 32970), there were vast improvements in both the position and height accuracies for the PPK data as shown in Figure 7 below. <Ref. VIII>



Method	X Error (cm)	Y Error (cm)	Z Error (cm)	XY Error (cm)	Total Error (cm)
RTK	22.84	28.74	29.66	36.71	47.20
PPK	0.75	0.67	1.27	1.01	1.62

Figure 7: The table shows average camera location and error estimates of photo centres where large errors from the RTK model (left side) were then corrected as demonstrated with the PPK model (right side). The small green circles (photos 1 – 159) within the RTK model are RTK-fixed while the coloured ellipses represent RTK-floats as shown in Figure 3. Note the measurement units shown in the respective model legends where RTK is in metres while PPK is in centimetres. With PSM 32970 held as the GNSS base, all photo centres were post-processed with KlauPPK Geomatics for positional improvement and synchronized by time correction before geoprocessing with Agisoft Metashape for PPK.

The error estimates as shown in Table 2 and Figure 7 provide a diagnostic assessment on the level of accuracies and improvement in position and height between the RTK and PPK methods. This is then validated with the PPK corrected data compared against the data captured by Total Station on an exposed road surface in the eastern part of the test case model (refer to Figure 8). In this test case, the accuracy of the PPK data was within 3 cm for horizontal and 5 cm for vertical which is ideal for topographic surveys.

RTK can be affected by the quality of communication while PPK provides more reliable and stable accuracy optimization and is less dependent on control points. The PPK workflow solution could be effectively applied to most AEC projects as they would obviously have large exposed ground surface (or bare earth) construction worksites for buildings, roads, pipelines, quarries, mining operations, processing plants and any other industrial complex.

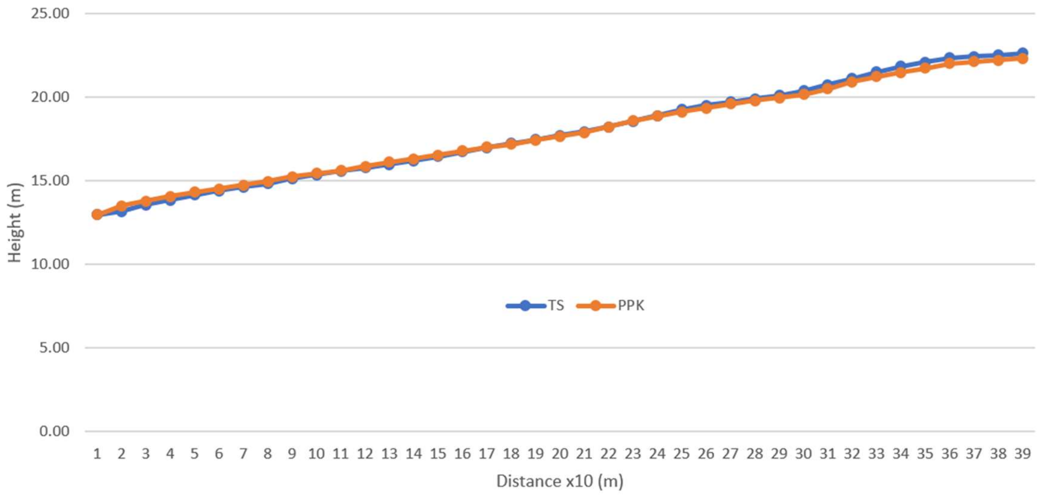


Figure 8: Profile of the road centreline showing height comparisons between data captured by Total Station (TS) and PPK aerial photogrammetry toward the eastern edge of the model. Validating the PPK data against the Total Station data capture of the exposed road surface with height differences averaging about 0.05 m over 390 m in distance and an average grade of 1 in 40 (or 2.5 %). This test case data confidently demonstrates a consistent pattern and the result including positioning can be considered reliable for construction worksites.

7.0 Practical application assessment for PPK Aerial Photogrammetry

The aerial photogrammetry survey can be carried out in 2D and 3D using the PPK workflow solution to enhance the speed and accuracy of data collection from large construction sites to support progress measurements and project control as follows: <Ref. II>

- Where it is crucial to consider the accuracy of the data to enable measuring distances, areas, slopes, or volumes. The GSD and any potential errors in the photogrammetry process can influence the precision of the measurements.
- By crafting detailed and captivating 3D visualizations from the aerial photogrammetry data, this can enable stakeholders, clients, and decision-makers to better comprehend the spatial attributes of the project or site. This in turn facilitates informed decision-making and efficient communication.
- By creating topographic maps from the aerial photogrammetry data, valuable insights can be extracted for land planning, engineering, construction, and environmental analysis, aiding in informed decision-making and enhancing project outcomes.
- Implementing routine aerial photogrammetry surveys allows monitoring and recording changes in the project site over time by tracking construction advancements, observing environmental modifications and pinpointing signs of ground instability and so on.

8.0 Discussion of migration toward PPK Aerial Photogrammetry for AEC worksites

As the AEC industry undergoes digital transformation, contractors are looking for innovative ways to become more efficient in order to gain a competitive edge. The construction worksite is changing and the PPK workflow solution is designed to minimize time in the field and make accuracy an easy and affordable option with minimal manpower and equipment for cost efficiency. The aerial drone can operate almost anywhere in areas that are difficult or dangerous to access on foot with traditional survey equipment. The drone can be flown over dangerous terrain and worksites with active machinery creating safety hazards and then the captured image data can be used to create accurate 3D models. <Ref. III>

The PPK aerial photogrammetry paves the way for maintaining comprehensive, up-to-the-hour records of construction sites. Regularly scheduled aerial survey missions yield invaluable insights into the status of a project, assist in identifying potential issues, and promote sound decision-making. Comparisons of 3D models and images taken over time ensure stakeholders that construction is proceeding as planned, adhering to safety standards, and matching design specifics. In addition, these records prove useful for tasks such as reporting, project management and resolving disputes.

PPK aerial photogrammetry provides real-time monitoring information such as accurate visuals and measurements as often as required to provide all teams with a real-time picture of a worksite for:

- Improved construction site reporting – drone captured survey data from monitoring large infrastructure works (1-5 km^2 or 100-500 hectares) repeatedly such as roads, pipelines, processing plants and others can boost accountability, communication and collaboration.
- Delivering greater project oversight – providing a holistic approach to project management with accurate and real-time survey information. For instance, resource management by tracking quantity and movement of earthworks material; reorganize and realign heavy equipment to priority areas; including environmental, security, safety and also legal issues, and so on.

9.0 Conclusion

The PPK aerial photogrammetry technologies have revolutionized the way spatial and spectral data are captured and analysed, offering numerous benefits and applications across various industries including the AEC industry. It is a valuable asset for documenting photographic evidence and monitoring changes in various contexts by generating high-definition images and accurate 3D models. Regular aerial survey missions enable well-informed decision-making, risk mitigation, and the development of targeted strategies to address various challenges.

The empirical results from the Mission 3 test case demonstrates that an optimized PPK workflow solution with aerial photogrammetry can deliver quality services and products in a timely manner with high accuracy and minimal operational costs. With proper planning, field operations can be streamlined to achieve high levels of positioning and height accuracies within a shorter period of time with minimal field time, manpower and equipment thereby reducing project costs.

This test case within the medium-sized Bunu Water Supply Project with a total area of 353 hectares has provided empirical evidence that aerial photogrammetry surveys using the optimized PPK workflow can be an economical alternative in terms of faster turnarounds, safer operations and maintaining survey-grade accuracies for construction projects. The same missions can be flown again later on over the same project areas using the same flight parameters for change detection and comparison against the baseline information. This optimized PPK workflow for aerial photogrammetry surveying is capable of collecting complete, reliable and well-organized baseline datasets to flow into the complex and layered process of building a digital twin.

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Acronyms and Abbreviations:

AEC	Architecture, Engineering and Construction
ALSL	Arman Larmer Surveys Limited
BIM	Building Information Modeling
CASA PNG	Civil Aviation Safety Authority, Papua New Guinea
CSRS-PPP	Canadian Spatial Reference System – Precise Point Positioning
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EXIF	Exchangeable Image File
GCP	Ground Control Point
GIS	Geographic Information System
GLONASS	GLObalnaya NAvigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSD	Ground Sampling Distance
IMU	Inertial Measurement Unit
KML	Keyhole Markup Language
LiDAR	Light Detection and Ranging
LNG	Liquefied Natural Gas
PNG	Papua New Guinea
PNG94	Papua New Guinea 1994
PNG08	Papua New Guinea 2008
PNGMG94	Papua New Guinea Map Grid 1994
PPK	Post-Processing Kinematic
RGB	Red Green Blue
RINEX	Receiver Independent Exchange
RL	Reduced Level
RMSE	Root Mean Square Error
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SfM	Structure from Motion
UAV	Unmanned Aerial Vehicle
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984
XYZ	Easting, Northing, Height

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