FEASIBILITY STUDY OF GNSS-ENABLED GCP MARKER FOR CONTROL ESTABLISHMENT FOR DRONE SURVEYING

A.F.P. Florin*, M.J.S. Gomez, L.C.S. Mabaquiao, R.V. Ramos

Department of Geodetic Engineering, University of the Philippines, Diliman, Quezon City, Philippines –
(albertflorin93, mjsgomez14)@gmail.com, (lsmabaquiao, rvramos)@up.edu.ph

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ABSTRACT:

This study explores the potential of GNSS-enabled Ground Control Point (GCP) markers as an alternative to traditional survey-grade receivers in observing GCPs for drone surveys. This is because an average drone flight and the observation period for rapid static are both 15 minutes. A GNSS-enabled GCP is already in the market through Propeller Aeropoints but is not available in the Philippines. Previous independent studies on the accuracy of such markers are limited as it is only focused on the accuracy. There are other considerations in using this technique such as the practicality of the marker, its usability with public Continuously Operating Reference Station (CORS) networks such as PAGeNet, and whether using it in conjunction with passive monuments will significantly affect the accuracy. The researchers designed and assembled a low-cost alternative using a u-blox module to determine the markers' applicability and effectiveness. This study was limited to using three (3) GCPs to simulate the minimum number required to georeference in 2D. Accuracy remains an important criterion so observations will be compared with known positions. Three drone surveys were conducted to further evaluate its performance. The marker achieved 3rd Order geodetic control and demonstrated up to one standard deviation of error using statistical analysis. However, the lack of control points affected the accuracy observed in the checkpoints. This study focused on low-cost GNSS-enabled GCP marker since the commercial Aeropoints markers are not vailable in the country. Implementing this methodology in drone surveying could potentially increase survey efficiency in the Philippines and aid in the country's cadastral mapping efforts.

1. INTRODUCTION

1.1. GNSS-enabled GCPs in Drone Surveying

This study investigates the potential of Global Navigation Satellite System (GNSS) enabled Ground Control Point (GCP) markers as an alternative to traditional survey-grade receivers in drone surveys. These are called "active markers" in contrast to the passive markers which still need to be observed. With average drone flights and rapid static observation periods both lasting 15 minutes, GNSS-enabled GCP markers offer a convenient and efficient solution. Although GNSS-enabled GCPs are available in the market through Propeller Aeropoints (Propeller, n.d.), they are not accessible in the Philippines. Previous independent studies have primarily focused on marker accuracy, but other factors such as marker practicality, compatibility with public Continuously Operating Reference Stations (CORS) networks like the Philippine Active Geodetic Network (PAGeNet), and the impact of using active markers alongside passive monuments on accuracy remain unexplored.

1.2. Scope and Significance of the study

The research focuses on the accuracy assessment of GNSS-enabled GCP markers in drone surveying. It was conducted at MMA-39 Baseline and CMC Hill in the University of the Philippines Diliman Campus using low-cost u-blox M8 GNSS receivers. The study primarily assessed horizontal accuracy and employed three GCPs to simulate the minimum requirement for georeferencing. The accuracy assessment included observations of a known control point and three drone surveys.

Furthermore, the study has implications for geodetic engineers, land developers, land management agencies, and other researchers. GNSS-enabled GCP markers can improve surveying processes, serve as substitutes for passive monuments, and facilitate efficient georeferencing in drone surveys. The findings can contribute to the development of new policies and protocols for land surveys, enhance survey efficiency in the Philippines, and aid in cadastral mapping efforts. Additionally, active markers have the potential to support geolocation in research sites and provide convenient and accurate surveying and mapping methodologies.

2. REVIEW OF RELATED LITERATURE

The Philippines has two control networks: a passive one with control monuments and an active one with CORS stations. The use of GNSS technology for surveying is not widespread in the country. Reyes et al. (2018) claimed that they were the first to use PAGeNet using RTK GNSS, whose study concluded that the said technique could observe geodetic control of First Order and below in minutes.

Leica Geosystems (2016) introduced the "SmartStation," which combines RTK capability with a Total Station, claiming accuracy up to 50 km from a reference station without manual control point observation. Propeller Aerobotics offers a similar technology with smart ground control points (GCPs) for UAVs, incorporating GNSS capabilities.

GCP markers are more familiar to Filipino surveyors as they require manual occupation and observation. They can be left on the ground to track their own position, potentially reducing

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[*] Corresponding Author

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waiting times during GNSS module initialization. Additionally, they can serve as the base receiver for Differential GNSS (DGNSS) techniques when PAGeNet is unavailable.

The Philippines has three reference systems in its cadastral database, and passive control networks will continue to be relied upon. Blick and Donnelly (2012) explained why active networks won't completely replace passive ones. Nevertheless, Balicanta (2015) demonstrated that GNSS techniques can achieve results comparable to traditional Total Station observations.

2.1. Active and Passive Network

Passive Control Networks in the Philippines use fixed markers with known coordinates categorized by accuracy. These markers can be disrupted by factors like earthquakes and other types of movements. The country is gradually shifting to Active Control Networks, mainly using CORS. These stations provide real-time updates for geodetic measurements. Despite the transition, there are challenges in expanding the active network, with fewer operating stations than the initial target. The transformation from passive to active control is ongoing but slow, with some areas still relying on outdated reference systems. Small firms and surveyors may lack access to the necessary technology, making passive control networks important in areas with limited resources.

CORS are geodetic reference stations that use GNSS signals to provide real-time, high-precision geographic data via the Internet. These stations are part of an "active" control network, regularly updating their coordinates to account for deformation. There is discussion about CORS potentially replacing Passive Control Networks.

In the Philippines, CORS is managed under PAGeNet by NAMRIA. However, there are only 42 to 62 operating stations, falling short of the planned 200 by 2020 (NAMRIA, 2016). This indicates a significant gap in achieving the desired number of operating stations.

2.2. GNSS in the Philippines

GNSS precision is measured using dilution of precision (DOP), with positional DOP (PDOP) combining x, y, and z errors. GDOP (Geometric DOP) accounts for satellite receiver geometry and time DOP (TDOP). DENR Memorandum Circular 2010-13, or the Manual on Land Survey Procedures, required recording GDOP, but LMC 2022-001 mandates recording only PDOP. At least 4 GNSS satellites are needed to determine a point's location, with more satellites improving precision. The Philippines is covered by GPS, GLONASS, BEIDOU, QZSS, and Galileo satellite systems.

GNSS provides precision but not accuracy due to its positioning methods. It requires an extended observation period for integer ambiguity resolution. Differential GNSS techniques are used to address this issue. Differential GNSS involves observing a known base point's position with two or more receivers, allowing precise position determination. There are two major types: static and kinematic, with the choice depending on the application.

2.3. Static and Kinematic GNSS Survey

In LMB Memorandum Circular 2022-001, or the Guidelines on the Use of Global Navigation Satellite System (GNSS) in the Conduct of Control and Land Surveys, Rapid Static surveying and Static surveying are defined as differential GNSS techniques for establishing control points. Rapid Static involves shorter simultaneous observations, while Static involves longer observations. The observation time depends on the baseline length, as outlined in Section 24 of DMC 2010-13.
High-precision positioning typically employs static GNSS, and both static and rapid-static are standard techniques for control point establishment. LMC 2022-001 specifies prerequisites for control establishment in isolated surveys, including the use of a single-frequency, dual-frequency, or multi-frequency receiver.

Operators must monitor observation status, including parameters like PDOP and satellite visibility, which are documented during observation. Receivers should be configured with all satellite constellations enabled, observing at least 10 satellites at any time with a minimum elevation mask of 15°. PDOP should not exceed 3.5, and measurements must be taken at a minimum epoch of 1 second, with data logged every 1 second.

Kinematic surveying methods include Real-Time Kinematic (RTK) and Post-Processed Kinematic (PPK). RTK provides real-time corrections from a base receiver for precise rover positioning, while PPK downloads data from both receivers for later processing. RTK requires inter-visible control points established through rapid-static GNSS, but it can achieve First-Order geodetic control accuracy when using reference stations like PAGeNet. Receiver requirements for RTK are similar to rapid-static GNSS, with added multi-GNSS capability and support for multiple radio channels.

RTK may be less effective under tree canopies, but under good conditions, it's comparable to surveys with total stations. In obstructed areas, a combined RTK-GNSS-Total Station survey is recommended.

2.4. Smart Ground Control Points (GCPs)

Smart stations, smart poles, and smart GCPs are GNSS-enabled tools for surveying. Propeller Aero's AeroPoints, an example of GNSS-enabled surveying equipment, with technical components like a solar panel, charger, GPS, and Wi-Fi, serve as versatile markers. They function as ground control points for UAV surveying, known base stations, and can create new marks, allowing for collaborative use to improve accuracy. While practical for many purposes, their 45-minute activation may be impractical in agricultural contexts; however, newer models require only 10 minutes.

AeroPoints offer high accuracy, up to 2 cm, through the Propeller PPK correction network. A study by Johansen and Raharjo (2017) reported a 6.1 cm RMSE for 10 AeroPoints. A study by sUAS News (2017) found no significant difference between AeroPoints and RTK receiver coordinates. In the absence of the Propeller Correction Network, non-proprietary GNSS processing methods, like PAGeNet or control point establishment, can achieve similar accuracy, though not available in the Philippines.

3. MATERIALS AND METHODS

3.1. Data and Materials

3.1.1. Survey Equipment and Hardware: The equipment and hardware used in the surveys is included in this section. The specifics for the marker is discussed in Section 3.2.1. The active marker is constructed using a u-blox M8 module, a generic GNSS antenna, and operated using a laptop. The marker is only a prototype, and connecting to the laptop allows the surveyors to more closely monitor and easily debug the data logging process when needed. Three of these markers serve as GCPs while natural GCPs will serve as checkpoints.

The location and observation of checkpoints was done through a PPK survey using three sets of Trimble SPS985 GNSS receivers and tripods. These receivers were used as they are readily available to the researchers and performs the functions needed for a PPK survey.

After checkpoints have been established, the drone survey is ready to be conducted. A DJI Mini 2 was used as the survey drone, with a photo presented in Figure 1. Some notable specs regarding the drone are presented in Table 1. An Android phone was connected to the drone controller to enable autopilot and ensure regularity in data collection.

Specification	Value
Camera Resolution	24 MP
Max Flight Time	31 mins
Weight	250 g
GPS Accuracy	±0.5 m Vertical, ±1.5 m Horizontal
Wind Resistance	8.5-10.5 m/s

Table 1. DJI Mini2 Specifications (DJI, 2020)

Figure 1. *DJI Mini 2 (DJI, 2023)*

3.1.2. Survey Equipment and Hardware: RTKLIB is the software that will be used for the recording of RINEX files from the active markers. It is free and open source, and the researchers have much control on how it runs. Emlid Studio is used for processing of the logged GNSS data. It uses RTKLIB as the processing core yet is more user-friendly to use and allows drag-and-drop interfacing. This allows speedy experimenting on various settings and RINEX data for the study.

Drone Harmony is the Android app used to set up the flight plan. This is one of the few free apps that supports auto piloting for the DJI Mini 2 while containing all required features such as grid missions for drone mapping. Agisoft Metashape was used to process the drone images to generate the orthomosaic map and drone survey report. The researchers have access to this software which allows fully customizable batch processing jobs to ensure the processing is controlled and repeated the same way. It also uses less resources than Pix4D, another photogrammetry software.

3.1.3. Data Collection: The GNSS survey is conducted to measure the coordinates of natural GCPs, which acted as checkpoints, along CMC Hill, UP Diliman. Three checkpoints were measured and processed by uploading it to the PAGeNet correction service. The three checkpoints are in (1) a post of the Corner Reflector, (2) a grass patch in a Monument, and (3) a Waiting Shed as mapped in Figure 6. Only these three features were observed since the CMC hill has a lack of distinct natural GCPs which is representative of a "rural landscape".

Flight images were gathered from the drone survey using a DJI Mini 2, referenced using coordinates observed by the active marker. The three checkpoints were post-processed together with the drone images in Agisoft Metashape to determine the positional error of the drone survey. These checkpoints were not included in georeferencing since they are only for validating the photogrammetry model. The positional error is the difference between the modeled position and the ground truth position and is included in the photogrammetry processing report.

The coordinate reference system that will be used in the study is WGS 84 [EPSG:4326] and projected to WGS 84 / UTM Zone 51N [EPSG:32651]. The study only considered the horizontal coordinates of different points in assessing the accuracy of the active marker. Height data of the points was not considered, but still included in the processing. Full reports on the PAGeNet Correction and Metashape photogrammetry processing is available upon request.

The design of the marker is a plywood base with the components attached to its surface. The GCP pattern was painted using latex acrylic paint with a smooth, glossy finish suitable for outdoor use. Trays for the electronic components were 3D-printed using PLA filament. The design of the model in Figure 2 served as the guide throughout the creation process.

3.2. Assembling the Active marker

This study aims to test the accuracy of surveys conducted using GNSS-enabled GCP markers, referred to as the "active marker". Its purpose is to use GNSS technology to observe its position and represent it physically as a GCP marker.

3.2.1. Design and Specifications: The active marker is patterned after AeroPoints marker and will follow a design shown in Figure 2—a 30 by 30 cm square plywood board with a GCP pattern painted on top. The four corners contain pinning holes so that the marker can be pinned to the ground. The antenna is mounted in the middle of the marker, positioning the Antenna Reference Point (ARP) just above the top of the plywood in the middle of the marker. The coaxial cable of the antenna is kept in a net pocket attached to one of the quadrants of the marker. This connects to the GNSS module, the u-blox M8, which is mounted to the board using the design in Figure 3. The dimensions of individual components are tabulated in Table 2.

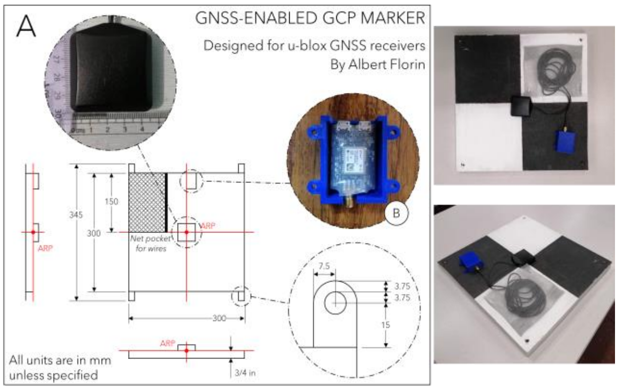

Figure 2. Schematic Diagram of the Active marker

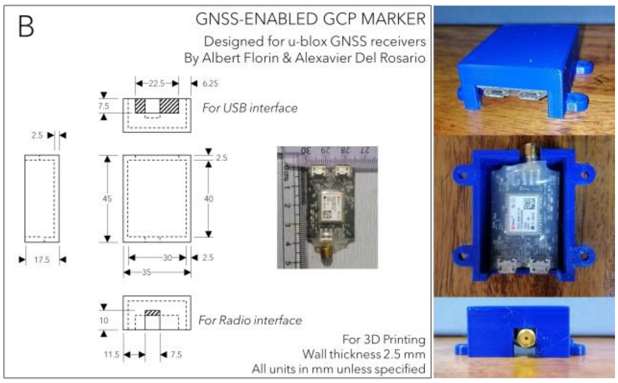

Figure 3. Schematic Diagram of the u-blox Mount

Component	Length x Width x Height (mm)	Weight (g)
Antenna	82.0 x 60.0 x 22.5	164
GNSS Module ublox M8	16.1 x 12.3 x 2.6	1.6
TOTAL	-	165.6

Table 2. Dimensions of Active Components of the Active Marker

3.2.2. Total cost of construction: The total cost of the construction for the three active marker is PHP 16,200. The cost of each component of the active marker, including the ublox M8 GNSS Module, Antenna, Plywood, Paint, Nails and Nets is shown in Table 3.

Component	Quantity	Amount in Peso
ublox M8	3	3,000
Antenna	3	11,700
Plywood	4 ft x 4ft x ¾ inch	800
Paint	2 x 500 ml	500
Nails and nets	12 x 5 inch	120
Nets	1 yard	80
TOTAL		**16,200**

Table 3. Price of each Components of the Active Marker

3.2.3. Usage: The marker has an embedded u-blox module which logs GNSS positioning data. Through this module, the active marker can log its own position simultaneously while a drone flight is happening. This simultaneous observation of GCPs while a drone survey is being conducted allows for the efficient use of time. This is not only because of doing two things at once, but also in how time-consuming manual observations of GCP coordinates is.

The active marker is used as a temporary control point. Its use as a temporary marker is done by pinning it to the ground, turning it on, then waiting for the drone flight to finish. However, when the need for reference systems other than WGS 84 arises, it can also be placed on permanent stations. By placing it over a known point, the survey is tied to the reference system of that point. Although coordinate conversion is possible, direct observations prove to be more accurate since not all cadasters are up to date. There are even times where coordinate conversion is not possible, which is the case for cadasters using local coordinate systems.
The active marker is used as the temporary control point for drone flights. An average drone flight lasting 15-30 minutes is the same time span the active marker needs for rapid-static post-processing to be applicable, in accordance to the minimum required observation periods indicated in the Section 24 of DMC 2010-13. Longer observations will lead to more accurate results since it ensures that the receiver is given enough time to collect enough satellite data to perform integer ambiguity resolution.

In addition to observation length, placement of the marker also affects its accuracy. It is recommended to place it in an open area with a clear view of the sky. This is not only for the drone to see the marker, but also for the marker to receive data from GNSS satellites. Although dual-frequency receivers provide corrections for this, the accuracy is still affected. Ideally, the marker must have a clear view of the horizon to receive as much data as possible. The placement of the active GCPs must adhere to the recommendations of GNSS surveying under LMC 2022-001 as it uses this technology.

For the data logging process, a laptop is connected to the active marker and using the RTKLIB STRSVR application. The study followed the setup guide by rtklibexplorer (2016). The use of the u-blox module enables the recording of GNSS positioning data. and provides UBX file output which can be easily converted to the open-source RINEX format using Emlid Studio. This allows the GNSS logs to be compatible with other receivers such as those from PAGeNet, which is used as the base station. Using the PAGeNet stations requires the download of RINEX files from both the marker and the base station. Additionally, PAGeNet offers an online correction service, however the RINEX files generated by the u-blox receiver is incompatible with their service.

3.3. Conduct of Surveys

3.3.1. Accuracy Assessment on MMA-39: The first test of the active markers was on MMA-39, testing all three markers against the control monument. The process is done by simply placing the marker on the monument, centering it, and activating it through the laptop as shown in Figure 4.

Figure 4. Active Marker on MMA-39

All three markers were placed on the monument and set to observe for 15 minutes. However, the other two observations were corrupted. This was conducted again, but MMA-39 A, C, and E were occupied at the same time once as shown in Figure 5. These data were rapid-static post-processed using the RINEX data from the Melchor Hall base station and the PTAG PAGeNet Station in Taguig, the closest PAGeNet station. These were processed in Emlid Studio.

In the conduct of these surveys, one person was assigned per marker. With three markers, three people were each responsible for their own observations.

Figure 5. MMA39 UP Baseline

3.3.2. Survey Area and Location of Ground Control Points: The location of the drone survey is in the CMC Hill, University of the Philippines, Diliman. The three active markers, namely Points 1, 2, and 3 in red were positioned near the corners of the CMC Hill, as seen in Figure 6. Moreover, the three checkpoints, Points 4, 5, and 6 in yellow, were also observed along the area through PPK.

Figure 6. Locations of control points along CMC Hill, UP Diliman

The yellow markers represent the natural GCPs observed and recorded in Figure 6. They were observed using a TRIMBLE receiver and post-processed by PPK through upload to the PAGeNet online coordinate computation service.

3.3.3. Setting up the Active Marker: The active markers were distributed in the three corners of the survey area as shown in Figure 6. A laptop is connected, RTKLIB STRSVR opened, and observation is started. The coordinates of these GCPs were determined through rapid static positioning in Emlid Studio. After a 15-minute observation period, the observations of the three markers were stopped. The data of the GCPs are then downloaded for post-processing.

3.3.4. Drone Survey: A DJI Mini 2 drone was used in the conduct of the drone survey. This survey required four people. Three people were assigned per marker along with one drone pilot. One of the people assigned to a marker was also tasked as the drone spotter. The drone will be controlled using Drone Harmony, whose interface is shown in Figure 7 with each "60" being a camera at elevation 60. The orange mark is the drone take-off and landing point. The flight parameters used are in Table 4. The Nadir camera angle in a single grid mission is used since this is an orthographic mapping project and not 3D modeling. A 60-m flying height was chosen for a high resolution and with 75% overlap, both as recommended by Aerotas (2019b), a drone survey processing company. They claim that any more data will only lead to increase in field time and expenses, but significant diminishing returns.

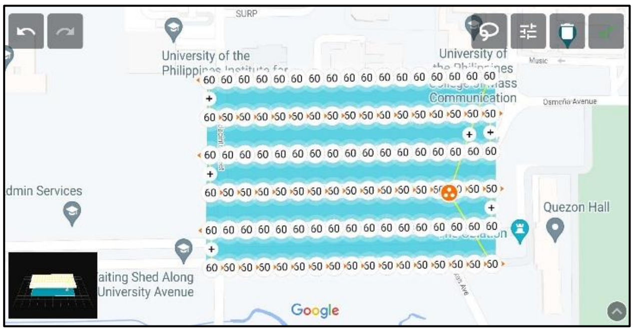

Figure 7. Drone Harmony Flight Plan

Parameter	Value
Drone	DJI Mini 2
Mission	Single Grid
Flying Height	60 m
Overlap	75%
Camera Angle	Nadir
Flying Speed	8 m/s

Table 4. Flight Parameters

3.3.5. GNSS Post Processing: The PAGeNet coordinate computation service did not accept the RINEX files converted from the UBX output of the active marker. Because of this, Emlid studio was used in post-processing the rapid static survey data. Emlid automatically converts the UBX files into RINEX and stores it in a folder. In line with LMC 2022-001, the elevation mask is set to 15° with all satellites enabled. The base station used for post-processing was PTAG of PAGeNet, the nearest station located in Taguig at 14°32'07.43'' N, 121°02'26.78'' E.

The TRIMBLE rover data was downloaded as T02 files, which was converted to RINEX using their proprietary software. These RINEX files were accepted by the PAGeNet online coordinate computation service, so this was used to compute the coordinates. The output coordinates were used in georeferencing during the photogrammetry processing through Agisoft Metashape. The parameters used for each GCP are Latitude, Longitude, Height, and the Standard Deviation as the precision.

3.3.6. Accuracy Assessment: The precision of all active marker observations was measured through its standard deviation. Since this is being used for drone surveys, the accepted precision should not be more than half the GSD of the flight.

The accuracy of the active marker on MMA-39 is measured by dividing the error by the baseline length to PTAG. Since the coordinates are in degrees, it was first converted to meters. This script converts the distance in degrees to radians, then multiplied by the average of the radius of curvature of the prime vertical, N, and the meridional radius of curvature, M:

$$N = \frac{a}{\sqrt{(1 - e^2 \sin^2 \varphi)}} \tag{1}$$

$$M = \frac{1 - e^2}{a^2} N^3 \tag{2}$$

where φ is the latitude, a is the equatorial radius, and e is the eccentricity (Jekeli, 2016).

Since the marker is not placed on a known point during the drone survey, the drone survey accuracy will be measured through the checkpoints. The error is part of the processing report generated by Metashape. Both accuracies should pass the 3rd Order Geodetic Control accuracy standard of 5cm per km, or 50 ppm, as stated in DENR Administrative Order 2007-29, or the Revised Regulations on Land Surveys.

4. RESULTS AND DISCUSSION

4.1. Survey Results and Performance of Active Marker

The study assessed the markers' performance using two base stations, PTAG and Melchor Hall, with MMA-39. For accuracy assessment, z-test was performed using the observed coordinate of MMA-39 using the two base stations, the expected value (known) coordinates of MMA-39, and error in observation. The data used is the hundreds of observation points for the 15-minute-long sessions, combined across all three sessions. The average coordinates and standard deviations of observations are recorded in Table 5.

Observation	Latitude	Longitude	Standard Deviation
MMA-39 (Known)	14°39' 18.8295''	121°03' 34.94441''	-
PTAG (PAGeNet)	14°39' 8.8299''	121°03' 34.94897''	0.0055, 0.0182
Melchor Hall	14°39' 18.9159''	121°03' 34.96837''	0.0004, 0.0004

Table 5. Comparison of the resulting coordinates from PTAG and Melchor Hall to MMA-39

Flight Number	Checkpoint	Z-score
Flight 1	Corner Reflector	4.270556688
	Monument	1.673365174
Flight 2	Corner Reflector	6.29587637
	Monument	3.190917005
Flight 3	Corner Reflector	10.02555531
	Monument	5.370299792

Table 6. Z-scores of Checkpoints

The coordinates of MMA-39 were compared to the observed position from PTAG (as listed in Table 5). The resulting difference in coordinates between PTAG and Melchor Hall was found to be 0.00457751" or 0.1411 meters. Given the known distance between PTAG and MMA-39 is 13,465.445 meters, the accuracy of this marker is calculated to be 10.5 parts per million (ppm). While this accuracy does not meet the requirements of 1st order surveys (which demand 10 ppm accuracy), it does satisfy the requirements for surveys with lower accuracy levels. It is important to note that since MMA-39 is categorized as a 3rd-order control monument, we can only conclude that its accuracy is suitable for 3rd-order control surveys.

Meanwhile, the z-test was conducted to evaluate if there's a significant difference between the expected and observed value of MMA 39 using the two base stations. By comparing the known coordinates of MMA-39 (expected values) with the observed coordinates obtained using PTAG as the base station. For the latitude, the z-score was close to zero, indicating that the PTAG coordinates are not significantly different from the expected values. However, for the longitude, the z-score was slightly above zero, suggesting a slight difference. Conversely, when Melchor Hall was used as the base station, the coordinates were found to be significantly different from the expected values. The z-scores, as shown in Table 7, were calculated to reflect these differences in the MMA-39 observations.

Base Stations	Lat z-score	Long z-score
PTAG	0.146	0.504
Melchor Hall	434.072	120.375

Table 7. Z-scores of MMA-39 Observations

Drone surveys involved three active markers for control. The resulting marker coordinates displayed a standard deviation ranging from 0.002 to 0.038 m. Each marker's position was changed between flights to simulate real-world scenarios. Checkpoints were used to gauge the error, revealing discrepancies ranging from 0.2874 to 1.0719 m.

Flight	Checkpoint	Error (m)	Error (px)
1	Corner Reflector	0.2874	0.375
	Monument	0.3340	0.259
2	Corner Reflector	0.4237	0.388
	Monument	0.6369	0.286
3	Corner Reflector	0.6747	0.118
	Monument	1.0719	0.126

Table 8. Summary of Checkpoint Errors

A z-test was performed to analyze observed and expected checkpoint coordinates, considering their standard deviations. Notably, all flights' checkpoints exhibited substantial differences between observed and expected coordinates, as indicated by the large z-scores as shown in Table 6.

4.2. Interpretation

The drone survey using active markers demonstrated that this technique is viable with low-cost drone and receiver equipment. Despite having a distant PAGeNet station and float solutions, the survey managed to achieve 3rd Order accuracy (1:20000). Using markers as base stations over a known point is recommended. The standard deviations of the markers' coordinates were mostly under 1 cm, except for two observations from the same marker suggesting systematic errors. Checkpoint errors ranged from 0.29 to 1.07 m, meeting acceptable accuracy criteria. However, they still differ significantly from expected values. The study by Blanco et al. (2017) using different equipment and more GCPs obtained better results, thus increasing the number of active markers is recommended. This also aligns with the recommendations by Pix4D (2018) and Aerotas (2019a).

5. CONCLUSION

This study used a low-cost constructed marker that demonstrated excellent precision and achieved accuracies up to 3rd Order Geodetic Control. The observation of MMA-39 using PAGeNet reached 2nd Order accuracy as per DAO 2007-29 requirements. The active marker also showed acceptable accuracy, being within one standard deviation of the known point. However, though reaching 3rd Order accuracy, the checkpoints displayed significant differences between observed and expected coordinates, likely due to reprojecting with only three GCPs instead of the standard five.

Active markers proved to be a time-saving solution for drone surveys, eliminating the need for manual observation and recording of GCP coordinates. They also offer a cost-effective alternative for georeferencing, as the low-cost marker used in the study demonstrated acceptable accuracies. Moreover, the marker's standard deviations indicated sufficient precision, within acceptable limits of half the drone's Ground Sampling Distance (GSD).

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