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PERFORMANCE EVALUATION OF GNSS TECHNIQUES IN CADASTRAL SURVEY WORKS

Muhd. Afiq D. Zaruni[1], Amir Sharifuddin Ab Latip[2*], Mohd. Asri Zahid[3], Nur Azlina Hariffin1[4] and M. Hezri Razali [5]

[1,2,3,4,5]*Centre of Studies for Surveying Science and Geomatics, Faculty of Built Environment, Universiti Teknologi MARA, Malaysia.*

[*]*amirsharifuddin@uitm.edu.my*

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ABSTRACT

Conventional cadastral surveying methods offer high accuracy and legal acceptance but face practical challenges in modern land management. These traditional approaches are time-consuming and demand extensive manual fieldwork, specialized instruments, and skilled personnel, leading to high costs. They also rely on line-of-sight between survey points, limiting their effectiveness in urban, heavily vegetated, or uneven terrains. As a result, conventional surveys may delay projects and struggle to scale for increasing demand. This study assesses the accuracy and efficiency of Global Navigation Satellite System (GNSS) techniques—specifically Single-Based Real-Time Kinematic (RTK) and Network-Based Virtual Reference Station (VRS)—compared against traditional Total Station methods in cadastral surveys. A field survey was conducted on a residential lot, with comparative analysis based on coordinates, bearing, distance, and area. The GNSS methods produced results closely matching the Total Station reference, with area deviations below 0.34%. Between the two GNSS techniques, VRS demonstrated slightly better accuracy and consistency. The findings endorse GNSS technology as a reliable, efficient alternative for cadastral surveying, particularly in areas with clear sky views. This supports more rapid, cost-effective land surveys without compromising accuracy, aligning well with contemporary land administration needs.

1. Introduction

Cadastral surveys are essential for land administration, property registration, and legal documentation of land ownership (Chan & Rajabifard, 2013). In recent years, the application of Global Navigation Satellite System (GNSS) has emerged as a transformative element in data acquisition for geospatial discipline, which offering significant advantages over traditional surveying methods (Smith, J. A., 2023). Conventional methods such as Total Stations offer high accuracy but are often time-consuming and labor-intensive, requiring a clear line-of-sight.

The emergence of Global Navigation Satellite System (GNSS) technologies has significantly enhanced cadastral surveying by enabling faster, more flexible, and cost-effective workflows (Rahmat et al., 2017).

GNSS-based surveying methods, including Single-Based Real-Time Kinematic (RTK) and Network-Based Virtual Reference Station (VRS), enable real-time positioning with improved accuracy and reduced operational costs (Deveci, 2009). These methods are increasingly used to address limitations in conventional surveying, especially regarding productivity and terrain adaptability. However, factors such as signal obstruction, atmospheric interference, and legal framework constraints can influence their effectiveness (JUPEM, 2016). Nowadays, the use of GNSS is becoming increasingly widespread, supported by the Circulars stipulated by Department of Survey and Mapping Malaysia. Based on JUPEM Circular and Survey Regulation such as the Circular of the Director General of Surveys and Mapping and Survey Regulation No. 5 and 6, Year 2009, it is evident that GNSS can be used for the establishment of Cadastral Reference Mark (CRM), facilitating the initial work of survey datum.

The study aims to evaluate the performance of GNSS-based methods in cadastral surveying by comparing with conventional Total Station technique. Specifically, the research assesses accuracy and efficiency of the Single-Based and Network-Based GNSS techniques, providing practical insights and best practice recommendations for boundary determination.

2. Methodology

The methodology starts with selecting a suitable study area, followed by data collection using three (3) techniques: Total Station, Single-Based RTK and Network-Based VRS. Three (3) reliable reference marks were established using the Total Station based on a Certified Plan using the Cassini Old coordinate system (Easting and Northing). Subdivision was performed by creating a preliminary plan, followed by site markings conducted using the Total Station first, then both GNSS methods. Key outputs included coordinates, bearing, distance, and area. The overall process is illustrated in Figure 1. The methodology employed in this study is structured into three (3) phases: study area, data acquisition and data processing.

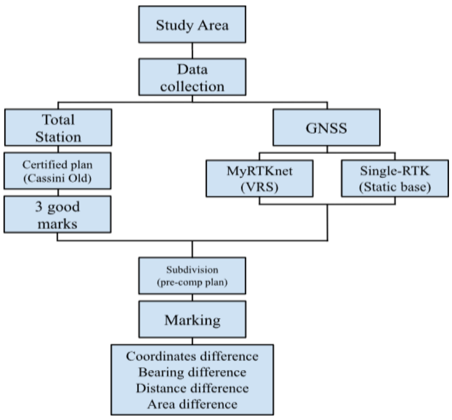

Figure 1. Research Methodology Flowchart

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2.1 Study Area

The study area is situated in Seksyen 7 **(Lot 1185)**, Shah Alam, within a low-density bungalow residential zone. This neighborhood predominantly consists of standalone houses, each surrounded by mature trees and well-maintained greenery. These bungalows often include open yards, terraces, and rooftops that offer clear, unobstructed views of the sky, as shown in Figure 2. The lack of high-rise structures in the area classifies it as an open-sky zone, making it highly suitable for GNSS observations.

Figure 2. Bungalow Lot 1185, Seksyen 7, Shah Alam (MyLot, 2024).

2.2 Data Acquisition

The preliminary subdivision (pre-computation) plan was prepared based on the Certified Plan. Figure 3 depicts the pre-computation plan created. A resurvey was carried out using a Total Station to establish traverse lines, identify three reliable reference marks and to re-establish any lost boundary markers. The coordinates for the three good marks were determined from the certified plan, which was based on the Cassini Old coordinate system. The new boundary marks were set out using coordinates derived from the certified plan. The positioning and planting of these marks were carried out using three (3) types of surveying methods: Total Station, Single-Base GNSS (RTK), and Network-Based GNSS (Virtual Reference Station). In data acquisition, i80 CHC GNSS was used for both methods: Single-Base GNSS (RTK) and Network-Based GNSS. The GNSS observation was performed based on standard guideline by Department of Survey and Mapping Malaysia.

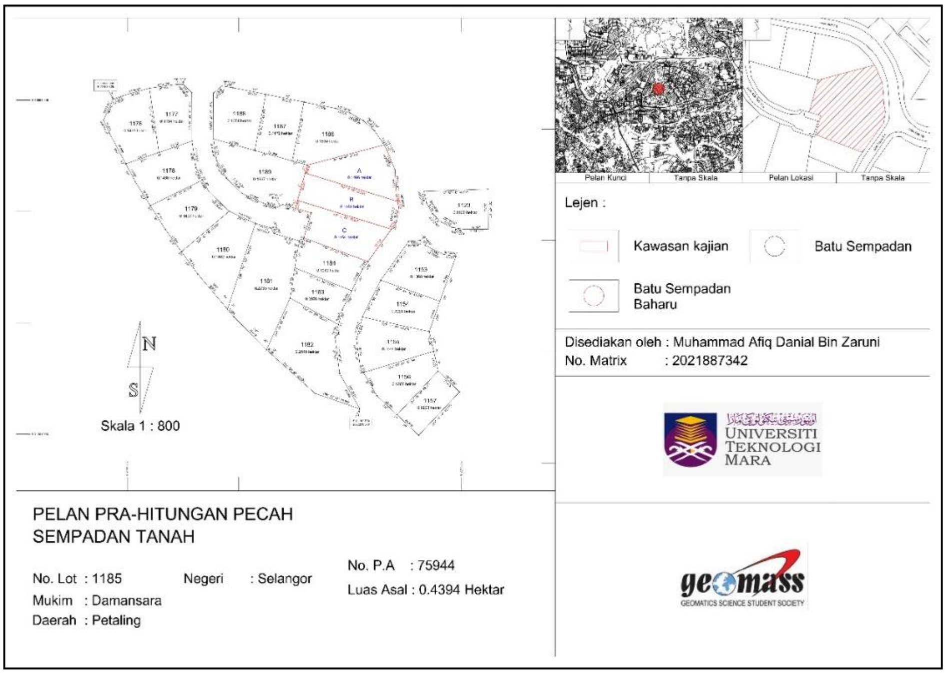

Figure 3. Generated Pre-computation Plan based on the Certified Plan.

2.2.1 GNSS-Based Stakeout and Accuracy Verification

The coordinates for the newly established boundary markers were obtained from the pre-computation (pre-comp) plan. Fieldwork involved using both Single-Based RTK and Network-Based (VRS) GNSS techniques in a stakeout process to accurately locate and position the physical boundary markers at their designated locations.

After completing the stakeout, GNSS measurements were taken at each marked point to verify the accuracy of marker placement. This verification process ensured that the boundary marks matched the intended design coordinates from the pre-computation plan. Both GNSS approaches were assessed to determine their accuracy and dependability under actual field conditions. The parameters used for this evaluation are outlined in Table 1 (Circular of the Director General of Surveys and Mapping No. 5, Year 2021).

Table 1. GNSS Observation Parameters for Stakeout Validation.

Parameter Criteria	Description
Observation Interval	Record data every 1 second
Real-time Recording	Every 5 seconds, with 10 readings used to complete one (1) epoch.
Elevation angle cut-off	15 Degree
Frequency used	Minimum dual-frequency
Observation Epochs	At least 2 epochs with a separate initialization.
Satellite Tracking & Dilution of Precision	At least 6 satellites with PDOP value below 7.
Coordinate Accuracy	3 cm (horizontal) and 6 cm (vertical).
Final Coordinates	Average from 2 epochs.
Antenna Type	Integrated

2.3 Data Processing

After establishing the new boundary marks using both Single-Based RTK and Network-Based (VRS) GNSS methods, a Total Station survey was conducted. The collected data was then processed in AutoCAD to reconstruct the boundary layout and accurately calculate the lot areas. The outcomes from the GNSS-based methods were subsequently compared to those from the Total Station to assess the consistency and accuracy of the different surveying techniques.

3. Data Analysis

3.1 Subdivision with Total Station

In this study, the conventional method using Total Station was utilized as the benchmark for subdivision work. Measurements such as coordinates, bearings, distances, and land areas obtained through this method served as the standard reference for stage analysis of data. Four (4) new boundary marks were placed according to the pre-computation plan, dividing the lot into three parts: Lot A, Lot B, and Lot C. The new boundary segments were labelled as 1, 2, 3, and 4. Table 2 presents the coordinates and measurements of these new boundary marks.

Table 2. Measurements of the new boundary marks using the Conventional Method.

Boundary Mark	New Boundary Marks Measurements				
	Coordinates (m) (N)	(E)	Line	Bearing	Distance (m)
1	-11013.372	-22270.922	1 - 4	107° 02′ 58″	69.581
2	-11033.044	-22276.398	2 - 3	107° 02′ 58″	70.587
3	-11053.74	-22208.912			
4	-11033.773	-22204.398			

3.2 Subdivision with GNSS Techniques

3.2.1 Single-Based Technique

The coordinates of the new boundary marks established using the Single-Based GNSS technique were read using a Total Station and redrawn in AutoCAD. The software was used to compute the area for the subdivided lots. Table 3 presents the measurement details for these new boundaries.

Table 3. Measurements of the new boundary marks by Single-Based GNSS.

Boundary Mark	New Boundary Marks Measurements				
	Coordinates (m) (N)	(E)	Line	Bearing	Distance (m)
1	-11013.405	-22270.949	1 - 4	107° 05′ 7″	69.583
2	-11033.129	-22276.42	2 - 3	107° 02′ 38″	70.596
3	-11053.821	-22208.924			
4	-11033.849	-22204.436			

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3.2.2 Network-Based Technique

A similar approach was applied for the Network-Based GNSS technique. The new boundary markers were measured with a Total Station and plotted in AutoCAD. Table 4 displays the corresponding coordinate values, bearings, and distances.

Table 4. Measurements of the new boundary marks by Network-Based.

Boundary Mark	New Boundary Marks Measurements				
	Coordinates (m) (N)	(E)	Line	Bearing	Distance (m)
1	-11013.418	-22270.954	1 - 4	107° 05′ 17″	69.571
2	-11033.128	-22276.422	2 - 3	107° 02′ 44″	70.604
3	-11053.824	-22208.919			
4	-11033.861	-22204.454			

Table 5 presents the area measurements (in hectares) for three lots (A, B, and C) obtained using three (3) different surveying techniques: Total Station, Single-Based GNSS, and Network-Based GNSS. The Total Station technique was used as the reference, and the analysis focuses on the absolute differences and percentage errors of the GNSS-based techniques relative to this reference.

Table 5. The Percentage Error between three (3) different surveying techniques.

Comparison of Total Station Technique and Single-Based Technique	Lot	Total Station Technique	Single-Based Technique	Absolute Difference	Percentage Error
		Area (Hectares)			Percentage (%)
	A	0.1466	0.1470	0.0004	0.27
	B	0.1464	0.1466	0.0002	0.14
	C	0.1464	0.1459	0.0005	0.34

Comparison of Total Station Technique and Network-Based Technique	Lot	Total Station Technique	Network-Based Technique	Absolute Difference	Percentage Error
		Area (Hectares)			Percentage (%)
	A	0.1466	0.1471	0.0005	0.34
	B	0.1464	0.1465	0.0001	0.07
	C	0.1464	0.1459	0.0005	0.34

Based on Table 5, for Lot A, the measured area values are very close across the three (3) surveying techniques. The highest value, 0.1471 hectares, was recorded using the Network-Based Technique, while the lowest value, 0.1466 hectares, was obtained using the Total Station Technique. This lot's overall variation in measurements is minimal, amounting to only 0.0005 hectares. For Lot B, the measurements obtained using the Network-Based and Single-Based Techniques are almost identical, differing by only 0.0001 hectares. However, the Total Station Technique yielded a slightly lower measurement with 0.1464 hectares. For Lot C, the highest measurement was recorded using the Total Station Technique with 0.1464 hectares, while the Single-Based and Network-Based Techniques produced identical, but slightly lower, values of 0.1459 hectares.

The data reveal consistent trends across the three surveying techniques. The Total Station method tends to produce slightly lower area measurements compared to GNSS-based methods. Between the GNSS techniques, the Network-Based method typically provides marginally higher values and demonstrates slightly better consistency. Despite these differences, all three (3) techniques yield highly comparable results, indicating a reliable level of precision for cadastral applications.

Analysis of the absolute differences and percentage errors shows that both GNSS techniques (Single-Based and Network-Based) have minimal deviations from Total Station measurements, with errors consistently below 0.35%. The Single-Based technique yielded percentage errors ranging from 0.14% to 0.34%, while the Network-Based technique showed similar deviations with improved consistency in Lot B (0.07% error). This suggests that the Network-Based GNSS method generally offers slightly more stable and reliable accuracy in cadastral surveying. Figure 4 displays the trend in area measurements for three (3) lots (A, B, and C) using three different surveying techniques: Total Station (reference), Single-Based GNSS, and Network-Based GNSS.

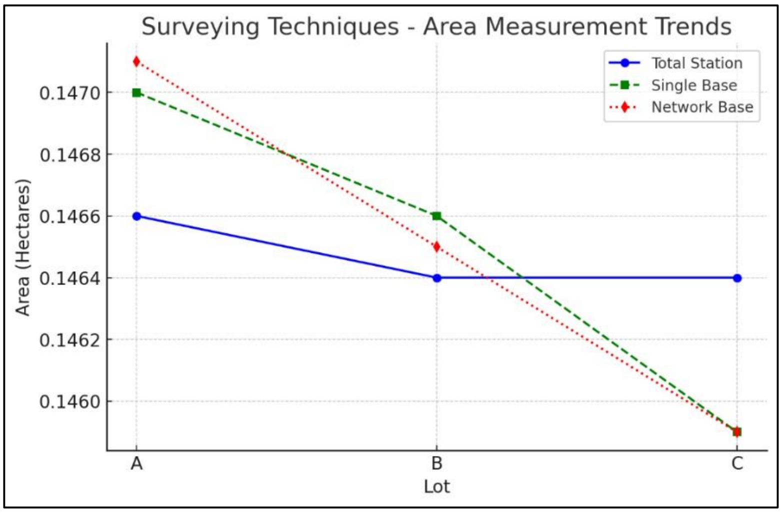

Figure 4. The Trend for Area Measurements for lots A, B, and C with Different Techniques.

For Lot A, both GNSS methods report higher area values than the Total Station, with Network-Based being the highest. In Lot B, the Single-Based GNSS remains slightly above both the Network-Based and Total Station. In Lot C, both GNSS methods measure lower areas compared with the Total Station (conventional method). The Network-Based GNSS displays a more consistent and gradually declining trend across all lots, while the Single-Based GNSS shows greater fluctuation, especially between Lots A and B. Despite these variations, the overall differences between methods are small, suggesting that GNSS-based surveying remains a reliable approach for area measurement, with Network-Based GNSS offering relatively greater consistency across different lots. However, two (2) critical factors influence the accuracy of all GNSS methods. First, the reliability of the Certified Plan coordinate system is essential; if these coordinates do not account for crustal deformation or ongoing tectonic movements, positional shifts may accumulate over time, leading to inaccuracies. Second, GNSS techniques require a clear sky view to minimize multipath errors reflections of satellite signals caused by nearby objects which can significantly degrade positional accuracy. Therefore, to ensure GNSS surveying is fully effective and legally defensible in cadastral work, it must be supported by up-to-date, velocity-corrected reference coordinates and conducted in environments with minimal signal obstruction. These measures are crucial to maintain both spatial accuracy and the integrity of land boundary determinations.

4. Conclusion

This study demonstrates that GNSS-based surveying techniques, particularly the Network-Based (VRS) method, provide a reliable and efficient alternative to support conventional method using Total Station for cadastral surveying applications. The findings of this research confirm that GNSS-based methods, especially the Network-Based VRS technique, are effective and dependable alternatives to the traditional Total Station approach for cadastral surveying. The VRS method demonstrated higher consistency and slightly better accuracy, making it particularly suitable for more complex or expansive survey areas. Meanwhile, the Single-Based RTK method also performed reliably and serves as a practical substitute in areas without access to VRS infrastructure.

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