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Integration of a Self-Developed GNSS Receiver with an Electronic Total Station for Urban Cadastral Surveying

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Abstract: ***This study presents an integrated urban cadastral surveying approach that combines a self-developed low-cost GNSS RTK receiver with a Leica TS02 electronic total station. GNSS RTK is employed for establishing control points and surveying open-sky areas, whereas the total station is used to measure detailed points in environments with limited satellite visibility. Field experiments conducted in Can Tho City demonstrate that the integrated approach improves measurement reliability, spatial coverage, and operational efficiency while satisfying the positional accuracy required for cadastral surveying. The proposed system provides a practical and economical solution for urban cadastral mapping, particularly in developing countries where cost-effective high-precision surveying is essential.***

Keywords: Self-developed GNSS Receiver; Urban cadastral surveying; GNSS RTK; Electronic total station; Cadastral mapping; VN2000 coordinate system

1. Introduction

Cadastral surveying plays an important role in land administration, urban planning, and property management, particularly in rapidly developing countries such as Vietnam, where rapid urbanization requires accurate geospatial data that are regularly updated. Nowadays many positioning techniques and methods are applied to the cadastral surveying, including GNSS RTK positioning has become one of the most widely used methods due to their capability to provide centimeter-level positioning accuracy in real time [1, 2].

Recent advances in GNSS positioning have significantly improved the applicability of real-time techniques for surveying and mapping. With the emergence of multi-constellation GNSS (e.g., GPS, GLONASS, Galileo, and BeiDou), several studies have reported improvements in positioning availability, convergence time, and reliability compared to single-constellation systems [3, 4]. Furthermore, network-based RTK and PPP-RTK techniques have been developed to extend coverage and mitigate distance-dependent errors, thereby enhancing positioning performance over larger areas [5, 6].

However, in urban environments, the performance of GNSS RTK method is significantly constrained by complex surrounding conditions. High-rise buildings and dense infrastructure create urban canyon effects that obstruct satellite signals and degrade satellite geometry, thereby reducing positioning accuracy. In addition, multipath effects caused by signal reflections from buildings, roads, and other surfaces introduce systematic errors and instability in RTK solutions [7, 8]. Frequent signal interruptions may lead to cycle slips and transitions between fixed and float solutions, ultimately affecting the reliability of real-time positioning. Recent studies have demonstrated that non-line-of-sight (NLOS) signals and limited satellite visibility significantly degrade GNSS positioning performance in urban canyon environments [9, 10, 11, 12]. Furthermore, RTK operation relies on continuous transmission of correction data via communication networks, which may be unstable in certain urban areas, resulting in latency or data loss [13, 14]. The technique is also less effective in confined or semi-obstructed environments, such as narrow alleys or locations close to buildings, where the accurate determination of cadastral boundaries is required. Consequently, the accuracy and consistency of RTK-derived coordinates in urban settings can vary significantly.

To address these limitations, this study proposes an integrated surveying approach that combines a self-developed low-cost GNSS receiver operating in RTK mode with an electronic total station for urban cadastral applications in Vietnam. In this framework, GNSS RTK is primarily employed for establishing control points and measuring features in open-sky conditions, while the total station is utilized to acquire detailed observations in obstructed or confined environments where GNSS performance is degraded. The integration of these two techniques enables complementary data acquisition, thereby improving both spatial coverage and measurement reliability. In addition, the use of a self-developed low-cost GNSS receiver aims to reduce equipment costs while maintaining acceptable positioning accuracy for cadastral purposes, which is particularly important in developing countries [15, 16].

The main contributions of this study are threefold. First, evaluation of the feasibility of integrating self-developed low-cost GNSS receiver with conventional surveying instruments is systematically evaluated under typical urban conditions. Second, the positioning performance of the proposed system is assessed through experimental measurements, with particular emphasis on accuracy, stability, and solution availability. Third, the results provide practical insights into the applicability of self-developed low-cost GNSS receiver for cadastral surveying in developing countries, where cost efficiency and operational flexibility are critical considerations.

2. Materials and Methods

2.1 Design and development of GNSS receiver

The developed GNSS receiver is based on the UM960 GNSS module, which supports multi-constellation and multi-frequency signal tracking, including GPS, GLONASS, Galileo, and BeiDou systems. The module is capable of providing real-time kinematic (RTK) positioning with centimeter-level accuracy under favorable conditions. The receiver was integrated with a custom-designed hardware platform, including a GNSS antenna, power management unit, and communication interfaces for data transmission and correction reception via NTRIP. The system was configured to output real-time positioning data and raw observations for further processing and analysis. The use of the UM960 module enables a cost-effective solution (approximately USD 200) while maintaining acceptable performance for cadastral surveying applications.

The UM980 GNSS module and the self-developed GNSS receiver shown in Figure 1.

a) b)

Figure 1: The UM980 GNSS module and the self-developed GNSS receiver

Compared to conventional geodetic-grade GNSS Receiver, the proposed system significantly reduces hardware cost while preserving essential RTK functionalities required for high-precision surveying.

The SurPad 4.2 software (Figure 2) was used for data acquisition and RTK control in this study. SurPad is an Android-based surveying application developed by Chinese GNSS manufacturers and widely deployed across multiple GNSS platforms. The software supports real-time kinematic (RTK) positioning, enabling centimeter-level accuracy through integration with GNSS Receiver and correction data services such as NTRIP. It provides a comprehensive set of surveying functions, including point measurement, stakeout, coordinate system management, and data visualization. In addition, SurPad offers a user-friendly interface and flexible communication options, allowing seamless connection with GNSS Receiver via Bluetooth or serial communication. These features make it suitable for various surveying applications, particularly in cadastral and engineering surveys.

Therefore, SurPad was selected in this study due to its compatibility with low-cost GNSS Receiver and its suitability for practical cadastral surveying applications in developing countries.

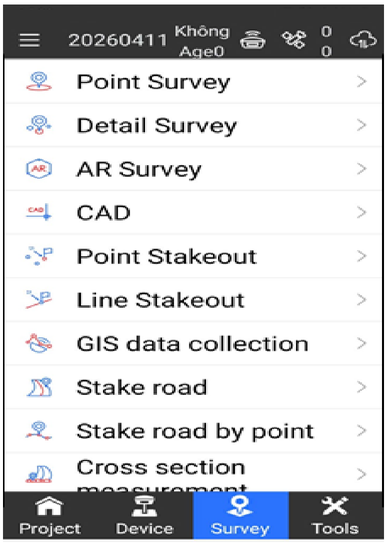

Figure 2: The SurPad 4.2 software runs on the Android operating system

2.2. Integration of GNSS Receiver and an Electronic Total Station for Urban Cadastral Surveying

To ensure accurate and reliable data acquisition under varying field conditions, this study employed an integrated surveying methodology, combining self-developed GNSS Receiver and the Leica TS02 total station. This integration was designed to exploit the complementary strengths of both technologies, where GNSS RTK provides rapid positioning in open-sky environments, while the total station ensures high-precision measurements in areas with obstructed signals or spatial constraints.

The integration of the GNSS receiver with the electronic total station was achieved using a specialized using specially machined connecting screws, ensuring that the antenna phase center of the GNSS receiver coincides with the vertical axis of the total station (Figure 3).

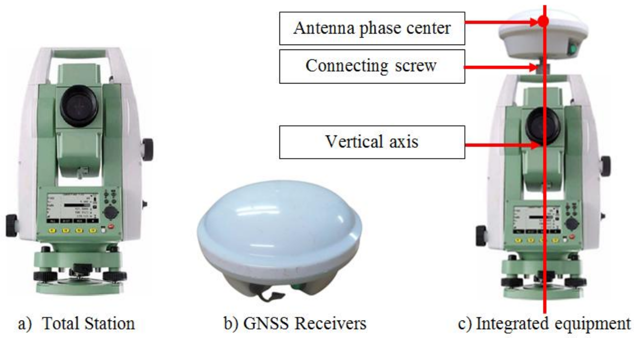

Figure 3: Integrating GNSS Receiver with total station

The workflow for urban cadastral surveying and mapping using the integrated equipment shown in Figure 4. In the proposed workflow, GNSS RTK was primarily used to establish control points and to perform measurements in areas with good satellite visibility. Real-time positioning was achieved using correction data transmitted via NTRIP, allowing centimeter-level accuracy under favorable conditions. These control points were subsequently used as reference stations for total station measurements.

The total station was employed to acquire detailed observations in environments where GNSS signals were degraded or unavailable, such as narrow urban streets, areas close to buildings, or locations with significant signal obstruction. By occupying the GNSS-derived control points, the total station measurements were directly referenced to the same coordinate system, ensuring consistency between datasets.

Data integration was achieved by combining GNSS RTK and total station observations within a unified coordinate framework. The collected data were processed and adjusted to evaluate positional consistency and accuracy. This hybrid approach enables continuous data acquisition across heterogeneous environments, improving both spatial coverage and measurement reliability.

Overall, the integration of GNSS RTK and total station techniques provides a practical and efficient solution for urban cadastral surveying, where neither method alone can fully satisfy the requirements for accuracy, completeness, and operational efficiency. Therefore, in this study, the Leica TS02 total station was integrated with the GNSS RTK system to ensure accurate and continuous data acquisition under varying field conditions.

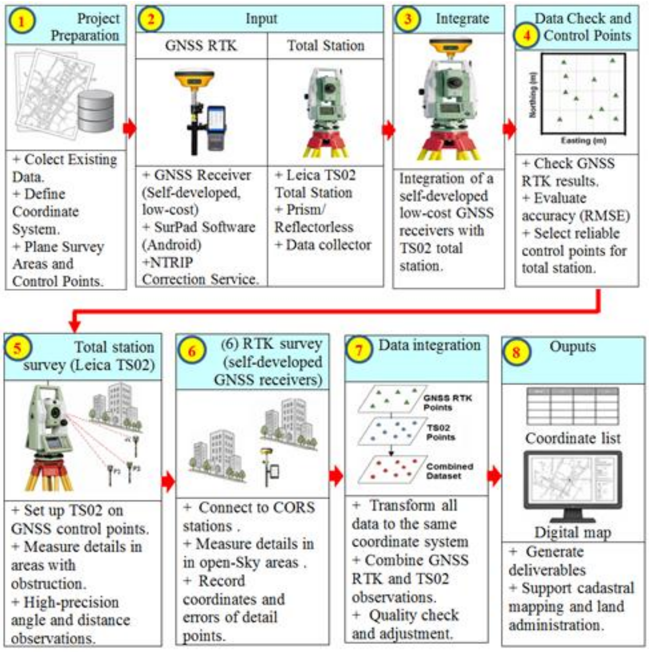

Figure 3. Workflow of integrated GNSS Receiver and total station (Leica TS02) surveying

2.3 Accuracy evaluation of a system integrating an electronic total station and a GNSS Receiver

In order to evaluate the accuracy of the integrated total station and GNSS receiver system for cadastral surveying and mapping, we performed field comparisons at co-located points. The research employed a Leica TS02 total station integrated with a self-developed GNSS Receiver, using GPS-established cadastral control points with predetermined accurate coordinates.

Table 1: Coordinate deviation of basic cadastral control points

No	Points	Known coordinates (m)		RTK measured coordinates (m)		Coordinate deviation (m)		Horizontal Positional error (m)
		X_{Kn}	Y_{Kn}	X_{RTK}	Y_{RTK}	δ_X	δ_Y	δ_P
1	GT02	1113153.565	584655.238	1113153.568	584655.231	-0.003	0.007	0.008
2	GT03	1113374.469	586421.754	1113374.466	586421.735	0.003	0.019	0.019

Table 2: Coordinate deviation of detailed points

Detailed points	Total station measured coordinates (m)		Coordinates measured by the integrated system (m)		Coordinate deviation (m)		Horizontal Positional error (m)
	X_{Kn}	Y_{Kn}	X_{RTK}	Y_{RTK}	δ_X	δ_Y	δ_P
1	1111367.937	586423.672	1111367.931	586423.684	0.006	-0.012	0.013
2	1111384.465	586419.046	1111384.472	586419.055	-0.007	-0.009	0.011
3	1111391.497	586431.786	1111391.511	586431.794	-0.014	-0.008	0.016
4	1111392.592	586447.225	1111392.604	586447.231	-0.012	-0.006	0.013
5	1111392.538	586474.670	1111392.528	586474.675	0.010	-0.005	0.011
6	1111368.784	586468.265	1111368.802	586468.280	-0.018	-0.015	0.023

Based on the coordinates determined by the self-developed GNSS Receiver and known coordinates of the two primary geodetic control points GT02 and GT03, the deviations in horizontal coordinates are calculated using the formula (1)

$$\left.\begin{aligned} \delta_X &= X_{Kn} - X_{RTK} \\ \delta_Y &= Y_{Kn} - Y_{RTK} \\ \delta_P &= \sqrt{\delta_X^2 + \delta_Y^2} \end{aligned}\right\} \quad (1)$$

where:

-X_{Kn}, Y_{Kn} - Coordinate components of a known point.

-X_{RTK}, Y_{RTK} - Coordinate components measured by RTK.

Deviations in the coordinate components of the two primary geodetic control points GT02 and GT03 shown in Table 1.

The coordinates of points GT02 (occupied station) and GT03 (backsight point) were inputted into the total station to perform detailed measurements based on the polar coordinate principle using the coordinate surveying program. These detailed points, whose coordinates had been previously

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determined, were marked with paint to calculate their coordinate deviations, shown in Table 2.

Based on the data in Table 2, the maximum coordinate deviations for the detail points are 0.018m for the X-component and 0.012m for the Y-component. According to the regulatory standard [17], the integrated system combining a GNSS receiver and an electronic total station is fully capable of being applied to detailed cadastral surveying in urban areas without the need to establish multi-level surveying control networks.

Field experiment and survey results

To obtain research results, a field experiment was conducted to perform cadastral mapping. The experimental survey area is located in Vinh Thanh town, Cantho city (Figure 6)

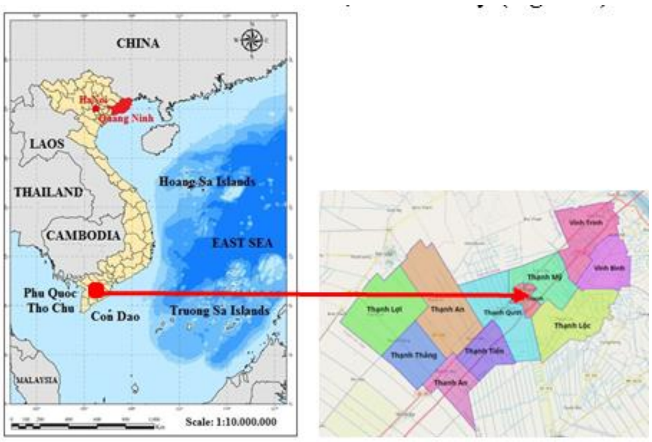

Figure 4: Experimental survey area

The study utilized the Vietnam National GNSS Network (VNGEONET), established by the Department of Surveying, Mapping and Geographic Information of Vietnam, and conducted measurements using the Virtual Reference Station (VRS) method and self-developed Receiver. The GNSS receiver is connected to the VNGEONET network to receive correction data, with the configuration parameters are shown in Table 3.

Table 3: Connection parameters for the VNGEONET Data Processing Center

No	Parameters	Value	Remarks
1	IP	14.238.1.125	Server Address
2	Port	2101	Connection Port
3	User name	TVGTKIOVN	-
4	Password	A0962598010	-

The positions of cadastral points were determined in the WGS84 coordinate system and then transformed into the VN2000 regional coordinate system using the following formulas (2):

$$\left.\begin{aligned} X_{VN2000} &= \Delta X_o + k(X + \varepsilon_o Y - \psi_o Z) \\ Y_{VN2000} &= \Delta Y_o + k(-\varepsilon_o X + Y + \omega_o Z) \\ H_{VN2000} &= \Delta Z_o + k(\psi_o X - \omega_o Y + Z) \end{aligned}\right\} \quad (2)$$

where:
- X_{VN2000}, Y_{VN2000}, H_{VN2000} are the coordinates in the VN2000 system;
- X , Y, Z are the coordinates in the WGS84 system;
and 7 parameters of Helmert transformation, include:
- ΔX_o, ΔY_o, ΔZ_o are the coordinate origin displacement parameters;
- ω_o, ψ_o, ε_o are 3 rotation angles of axes corresponding to X, Y, Z.
- k is scale factor;

The coordinate components X, Y, and Z in the WGS84 coordinate system are calculated using the following formulas (3):

$$\left.\begin{aligned} X &= (N+H)\cos B.\cos L \\ Y &= (N+H)\cos B.\sin L \\ Z &= [N(1-e^2)+H].\sin B \end{aligned}\right\} \quad (3)$$

where:
B is the geodetic latitude; L is the geodetic longitude; H is the geodetic altitude
N is the radius of the first vertical circle at the point of consideration:
e is the first eccentricity of the ellipsoid.

The seven-parameter Helmert transformation from the WGS84 to the VN2000 coordinate system was officially published by the Ministry of Natural Resources and Environment of Vietnam.

The coordinate transformation parameters for Can Tho City (with a central meridian of 105°45') are shown in Table 4.

Table 4: Coordinate transformation parameters for Can Tho City

No	Parameters	Value
1	Central meridian	105°45'
2	ΔXo	-191,90441429 (m)
3	ΔYo	-39,30318279 (m)
4	ΔZo	-111,45032835 (m)
5	ω_o	-0,00928836"
6	ψ_o	0,01975479"
7	ε_o	-0,00427372"
8	k	1,000000252906278

The coordinates of several cadastral points, acquired via self-developed GNSS Receiver and transformed into the VN2000 regional coordinate system in Can Tho City , are shown in Table 5.

Table 5: Coordinates of several cadastral points measured using self-developed GNSS Receiver.

No	X_{VN2000} (m)	Y_{VN2000} (m)
1	1131568.700	543420.400
2	1131573.110	543424.620
3	1131576.350	543427.730
4	1131579.600	543430.850
5	1131582.850	543433.960
6	1131586.090	543437.080
7	1131589.340	543440.190
8	1131592.590	543443.310
9	1131595.830	543446.420
10	1131599.080	543449.540
11	1131602.330	543452.650
12	1131605.580	543455.770
13	1131608.820	543458.880
14	1131612.070	543462.000
15	1131615.320	543465.110
….	………	……….

Table 6 shows the coordinates of several cadastral points in Can Tho City, acquired using a total station in the VN2000 regional coordinate system.

Table 6: Coordinates of several cadastral points measured using Electronic Total Station

No	X_{VN2000} (m)	Y_{VN2000} (m)
….	………	……….
219	1131603.100	543506.330
220	1131596.210	543508.070
221	1131586.440	543510.540
222	1131575.870	543500.550
223	1131571.510	543496.430
224	1131570.090	543495.090
225	1131569.210	543494.260
226	1131567.760	543492.890
227	1131567.150	543492.310
228	1131562.780	543488.190
….	………	……….

The coordinates of the cadastral points, measured using GNSS Receiver and total stations, were combined and saved into a text file (.txt) after being transformed into the VN2000 coordinate system. To construct the cadastral map and prepare the parcel technical dossiers, we utilized the Vietnamese-developed TOPO software and MicroStation. Specifically, the TOPO software was used for cadastral mapping (Figure 5), while MicroStation was employed for cadastral records management.

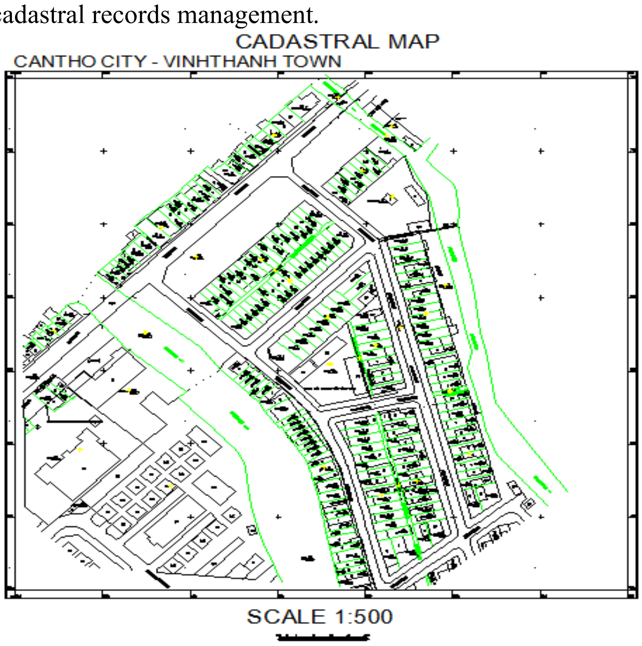

Figure 5: The cadastral map was produced using TOPO software

After being created using TOPO software, the cadastral map is exported to .DXF format and then imported into MicroStation for editing, database construction, and cadastral documentation.

4. Conclusion

The developed integrated surveying system successfully combines a self-developed GNSS RTK receiver with a Leica TS02 electronic total station for urban cadastral surveying. Experimental results demonstrate that the system satisfies the required positional accuracy for cadastral mapping while improving measurement continuity in GNSS-obstructed environments. The approach reduces dependence on conventional multi-level control networks, thereby improving operational efficiency and lowering survey costs. Future work should evaluate the system under a wider range of urban environments and compare its long-term performance with commercial geodetic-grade GNSS receivers.

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