Performance of Network-Based RTK GNSS for the Cadastral Survey in Thailand

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Abstract
In Thailand, a network of GNSS Continuously Operating Reference Station (CORS) has been operating as a Network-based Real Time Kinematic (NRTK) GNSS positioning solutions since 2008. The Department of Lands designs a Thai-NRTK system mainly for GNSS cadastral survey using the Virtual Reference Station (VRS) as its positioning concept. The current Thai-NRTK consists of 114 GNSS CORSs covering only some parts of Thailand. The CORS spacing ranges from 25.1 km to198.6 km. According to previous studies, the performance of NRTK-GPS positioning determination in Thailand is strongly depending on the dimension of the triangular CORS locations; known as a "loop". This research aims to examine the horizontal position performance of this Thai-NRTK GNSS positioning solutions as a quality indicator for GNSS cadastral surveying. The test was carried out with quite a large number of test samples (total of 2,122 points) and where every loop is separated into 4 test groups with differing the station distances starting from the loop spacing of: 30 km to 50 km, 50 km to 70 km, 70 km to 90 km and 90 km to 110 km, respectively. The positioning performance test is conducted in two main folds; namely, positioning accuracy and time to resolve its solutions. On positioning accuracy, the test results show that the spacing of every tested loop achieves the accuracy in accordance with the cadastral surveying requirements. This proves that the Thai-NRTK GNSS positioning network and technique is well-designed and suitable for cadastral positioning within its coverage areas. On time to resolve fixed solution, the test results indicate that the 'time to first fixed' and the 'rate of the horizontal position jump' increase with longer loop distance; whereby only loop length of 30 km to 50 km has 100% success 'rate of ambiguity-fixing' solutions; therefore, in order to achieve a high reliable performance positioning from the Thai-NRTK GNSS solutions for cadastral survey in Thailand, it is recommended that the reference stations shall be kept within 50 km.

1. Introduction

The cadastral survey in Thailand is one of the main procedures to acquire the Land Title Deed from the Department of Lands (DOL) (Ministry of Interior, 1954 and Spelde, 2019). This survey technique was designed for locating the land parcel boundaries and computing its area. According to the DOL regulations, the cadastral survey is divided into two categories; namely, first-class and second-class cadastral surveys respectively (Ministry-of-Interior 1954). These two cadastral survey techniques must comply with DOL regulations that defines the horizontal positioning accuracy standard i.e. shall be better than 1:3000 (Department-of-Lands, 1999) or achieve within 4 cm accuracy because the dimension of DOL boundary mark is 8 cm (see Figure 1) (Department-of-Lands, 2018). The first-class cadastral survey must provide coordinates according to the DOL-UTM coordinate system based on the Everest1830 ellipsoid and Indian 1975 datum (Department-of-Lands, 2004) from the open-traverse survey by using the total-station or theodolite equipment (Ministry-of-Interior, 1954).

Figure 1: Specification and description of a boundary marker (Department-of-Lands, 2018)

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The first-class cadastral survey is always costly and time consuming; while, the second-class survey can determine its own pseudo-coordinate and does not require to related to the DOL-UTM coordinate system (Ministry-of-Interior, 1954). The disadvantage of the second-class cadastral survey is that the land parcels will always have no real coordinate system.

Since 2008 (Charoenkalunyuta et al., 2012a, 2012b and Charoenkalunyuta and Satirapod, 2014), Thailand has established and operated CORS for VRS-NRTK GNSS system (Rizos, 2007 and Cina et al. 2015) with the main purpose of developing a new cadastral surveying technique for DOL (and of replacing the first and second classes cadastral survey techniques) (Department-of-Lands, 2016). Currently, the Thai-NRTK system (Charoenkalunyuta et al., 2012b) consists of 114 GNSS CORSs (as of January 2019) located in some parts of Thailand where the GNSS CORS spacing is between 25.1 km to 198.6 km. Each station baseline forms a CORS triangle (known as loop) containing 143 loops totally (see Figure 2).

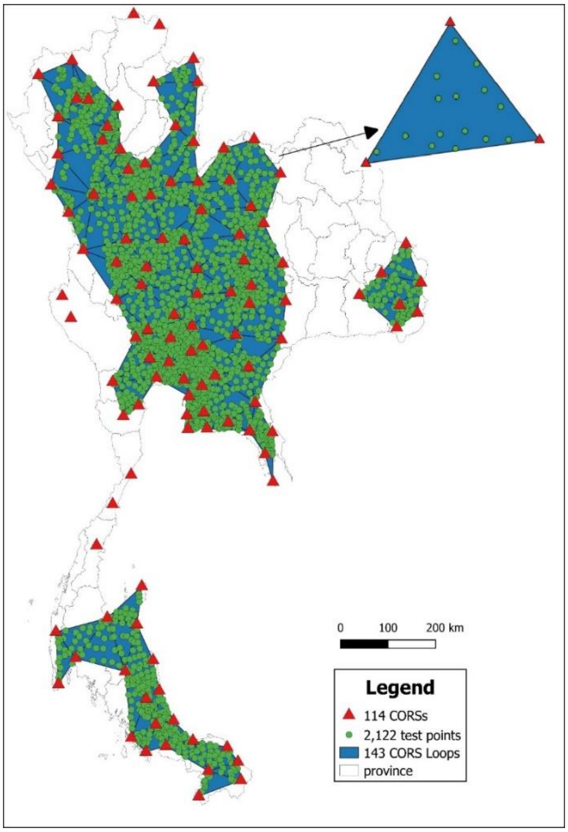

Figure 2: Diagram of test points, CORSs and CORS loops in Thailand

Janssen et al., (2011) illustrates the RTK GPS processing technique methodology to improve the existing cadastral survey control infrastructure carried out in New South Wales, Australia; whereby, they stated that the RTK GPS technique was well suited to improve the survey marker for cadastral surveyors. Moreover, Charoenkalunyuta et al., (2012a) had tested the performance of NRTK-GPS in Thailand in off-line mode using only GPS observations by collecting data on 31 consecutive days to form four different loop sizes (spacing from i.e. 10 km to 20 km, 30 km to 50 km, 50 km to 60 km, and 60 km to 80 km) and positioning performance test was carried out on 8 tested points. It was concluded that the performance of NRTK GPS solutions in Thailand is highly depending on the loop size. The smaller loop size provides the better performance. Nevertheless, recently, the new navigation satellite systems are also available in Thailand (i.e. GLONASS, Galileo, BeiDou and QZSS) (Andrei et al., 2015). This research aims to examine the effect of loop size towards the horizontal position performance of Thai-NRTK GNSS positioning solutions for the cadastral survey in Thailand in actual environment. The test had used large number of test points spreading all over Thai-NRTK GNSS covering area. The following sections start from introducing the Thai-NRTK GNSS system for the cadastral survey, explicitly explaining the methodology, providing and discussing the performance test results and finally concluding some remarks.

2. Thai-NRTK GNSS System for Cadastral Surveying

Thai-NRTK GNSS system for the cadastral survey consists of three main sections (Charoenkalunyuta and Satirapod, 2010): 1) Continuously Operating Reference Station (CORS); 2) a control center; and 3) the rovers (see Figure 3). The first section comprises of 114 CORSs (as of January 2019) located in quite several regions in Thailand and could form 143 loops where the loop inter-station spacing could be varied from 25.1 km to 198.6 km. Every CORSs is equipped with a multi-frequency, GNSS, geodetic receivers. Its antenna is mounted at a good observed condition without any satellite signal blockages above the horizon; therefore, multipath effect may be neglected (see Figure 4). The second section is the control center located at Department of Lands (DOL), in Nonthaburi. This control center produces the Thai-NRTK GNSS (GPS, GLONASS, Galileo and Beidou) solutions using the CHC Precision Positioning Service Software (CPS) software (CHC, 2019) where the Virtual Reference Station concept (VRS) (Wanninger, 1999 and 2002) is selected as the Thai-NRTK GNSS solutions for cadastral surveying. The third section contains the rovers (user section) and is mainly multi-frequency, GNSS geodetic receivers, particularly to observe Thai-NRTK GNSS solutions.

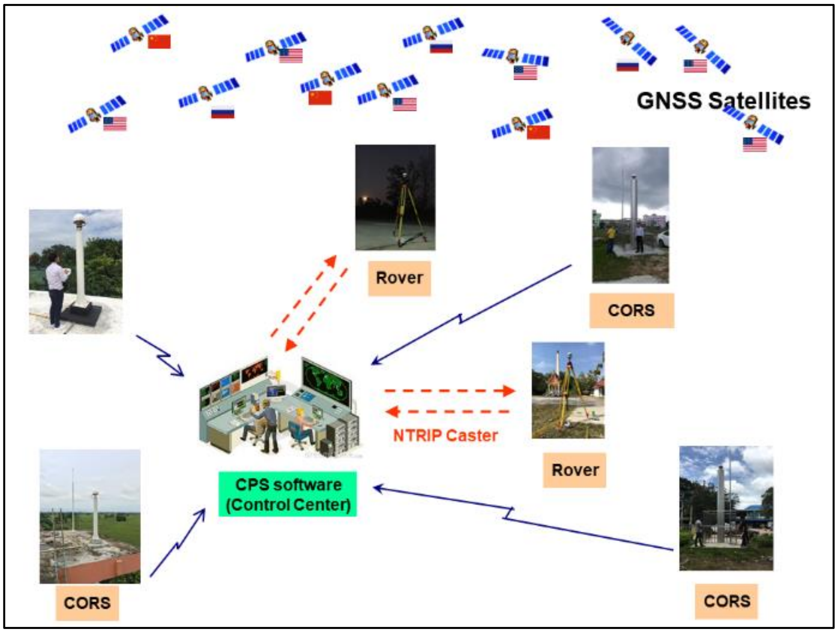

Figure 3: A operation schematic of the Thai-NRTK GNSS system for GNSS cadastral surveying

Figure 4: Example of GNSS CORS installations

3. Methodology

This research methodology comprises of four main steps as illustrated in Figure 5. The first step is to retrieve the Thai-NRTK GNSS (VRS) and static observation at each designated test point. The second step involves establishing the reference coordinates; following by the third step on comparison between the reference and the Thai-NRTK GNSS (VRS) coordinates. The final step was to classified test points by the analyzing the size of the achieved CORS loop. Each determination step is explicitly described as followings.

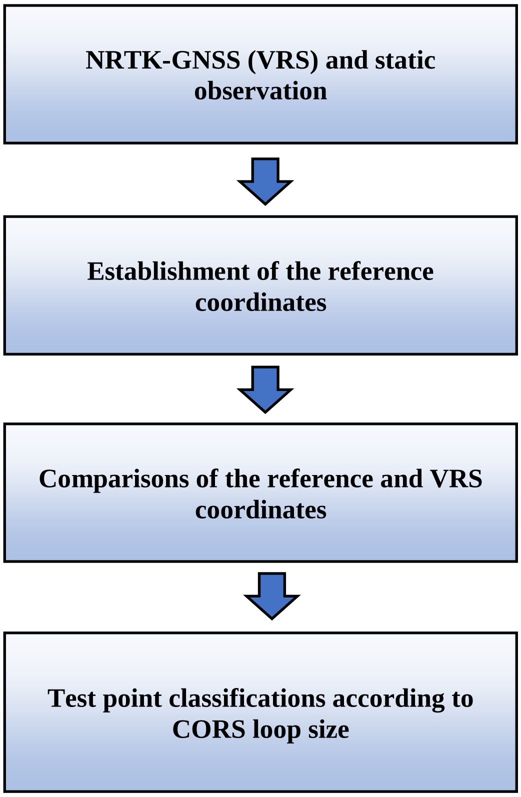

Figure 5: Research methodology

3.1 Thai NRTK GNSS (VRS) and Static Observation

In order to ensure the consistency of final Thai NRTK GNSS positioning solutions, the observation environment of every chosen test points were in an appropriate GNSS observation location (see Figure 6). Each loop contained approximately 12 to 15 test points; therefore, the total number of tested points in every constructed loop in this study becomes 2,122. The measurements at each test points were carried out using the multi-frequency, GNSS, geodetic receiver to observe the real-time Thai-NRTK GNSS solutions. The measurement period was planned on a clear sky day-time starting from Dec-2017 to Feb-2018 (also known as winter in Thailand). The VRS corrections were sent to the GNSS rover through mobile phone (sim-card) using a NTRIP Caster protocol at a 1-second "sampling" rate. This resulted 900 epoch-observations with the new initialization at 60 seconds repeatedly. The static observations of 90-minutes were performed during the same period and in coherence with the VRS observation mode.

3.2 Establishment of the Reference Coordinates for Each Test Point

In order to obtain accurate test points, the reference (or a ground-truth point) coordinates has to be determined from the 90-minutes GNSS static observation data by using a commercial post-processing software; Trimble Business Center (TBC) version 4.1 (Trimble, 2019), as a processing tool. At each test point, a static solution was obtained by using 30-second observations and applying a standard processing baseline procedure. The two nearest CORSs of each tested point were selected as its fixed stations (Okorocha and Olajugba, 2014) and the IGS GPS and GLONASS final orbits and satellite clock corrections (IGS, 2019) were also introduced in this data processing algorithm. The coordinate accuracy of every tested point was agreed to be within 2 cm; therefore, these coordinates of an individual test point can be used as reference coordinates for subsequent analysis.

3.3 Comparisons of Reference and Thai-NRTK GNSS (VRS) Coordinates

When the reference coordinates were completely established, the Thai-NRTK GNSS (VRS) coordinates were later compared with the reference coordinates in horizontal component for each test point. Each test point, the quality measured indices were computed including: Root Mean Square Error (RMSE) of all data (at 900 epochs), RMSE of every 30 epochs, rate of ambiguity-fixing and rate of position jump in horizontal position. Time to First Fixed and PDOP (Position Dilution of Precision) were also collected from the individual VRS survey points. It is noted that, 'The rate of ambiguity-fixing' is the percentage of ratio between the ambiguity-fixed solutions and all data used in the processing, while 'The rate of the horizontal position jump' is the percentage of ratio between ambiguity-fixed solutions that fell outside an 8-cm error circle and 'Time to first fixed' is defined by the period from the initial time until the fixed solution is successfully fixed. Nevertheless, 'the variation of the VRS coordinate' can be interpreted by the RMSE for the Horizontal Position of every

30-epochs chart (RMSE-h trend over time is as shown in Figure 7).

Figure 6: Example of test point locations

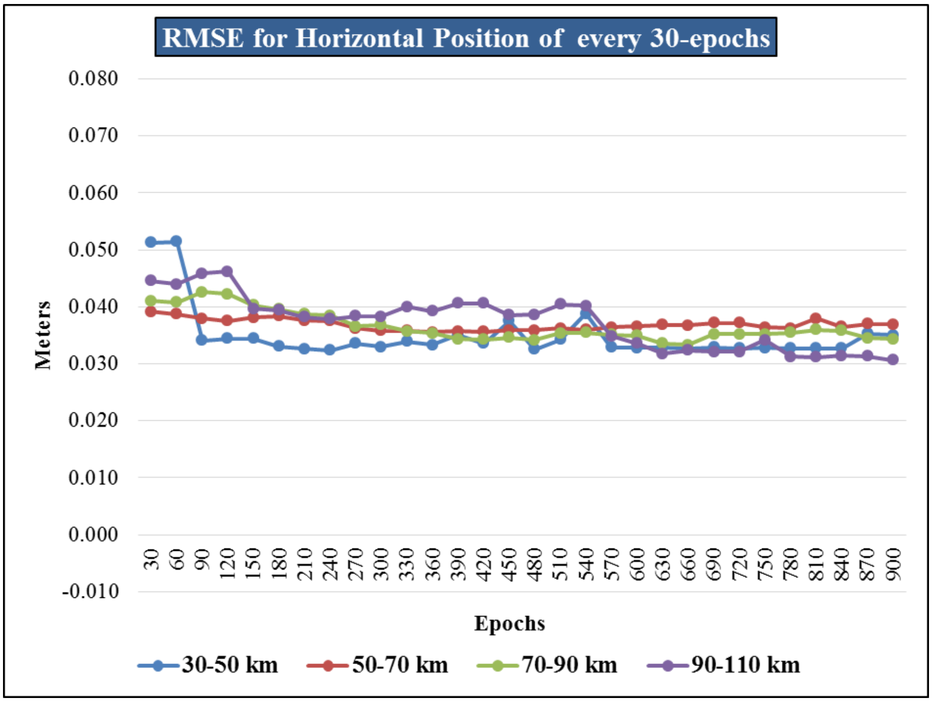

Figure 7: Average of every 30 epoch RMSE for Horizontal Position for each loop size

3.4 Classification of Test Points by the CORS Loop Size

This research aims to examine the effect of CORS loop size towards the horizontal position performance of Thai-NRTK GNSS positioning determinations. Therefore, all CORS loops were grouped into four different categories i.e. 30 km to 50 km, 50 km to 70 km, 70 km to 90 km and 90 km to 110 km; as shown in Table 1, based on the averaged CORS triangle spacing. The test results and the analysis of the Thai-NRTK GNSS solutions are described in the following section.

Table 1: Number of loops and test points

Loop size (km)	No. of Loops	No. of test points
30-50	16	238
50-70	47	692
70-90	54	802
90-110	26	390
Total	**143**	**2,122**

Table 2: Summary of the performance of Thai-NRTK GNSS for each loop size

Loop size (km)	Rate of ambiguity-fixing (%)	Time to First Fixed (s)	PDOP	Rate of Hor. position jump* (%)	Highest of Hor. position jump (m)	RMSE Hor. position (m)
30-50	100.0	16	1.5	2.5	0.130	0.032
50-70	98.3	21	1.5	3.6	0.348	0.035
70-90	98.0	32	1.4	3.4	0.223	0.035
90-110	96.2	34	1.4	3.1	0.232	0.035

*Remark: *The position jump is computed based on the ambiguity-fixed solutions that fall outside an 8-cm error circle.*

4. Test Results and Discussions

According to the loop categories presented in Table 1, the performance of Thai-NRTK GNSS horizontal position in VRS mode is characterized by seven performance indicators: 1) Rate of ambiguity-fixing; 2) Time to First Fixed;3) PDOP;4) Rate of horizontal position jump;5) Highest of horizontal position jump;6) RMSE in horizontal position; and 7) The variation of the VRS coordinate. However, it should be noted that all indicators are the average values of the solutions obtained from the number of test points in each loop size. These indicators are shown in Table 2 and the variation of the VRS coordinate is illustrated in Figure 7.

Table 2 shows that the horizontal RMSE of all loop size are below 4 cm. This can conclude that the Thai-NRTK GNSS solutions of all different loop sizes meet accuracy requirement for the cadastral survey in Thailand. Thus, the Thai-NRTK GNSS technique is well suited for the cadastral survey in Thailand. However, Table 2 also indicates that the ‘Time to first fixed’ the ‘rate of the horizontal position jump’ and the ‘highest horizontal position jump’ are increased when the loop size becomes larger. Furthermore, the ‘rate of ambiguity-fixing’ of solutions according to the loop size of 30 km to 50 km, 50 km to 70 km, 70 km to 90 km and 90 km to 110 km was 100%, 98.8%, 98.0% and 96.5% respectively. This shows that only loop size of 30 km to 50 km. contains 100% for the ‘ambiguity-fixing rate’; although other rates decrease when the loop size is larger. Figure 7 explains that variations of computed VRS coordinates also depend on the loop size, where smaller loop helps to reduce positioning variations except for during a short observation period (at 30-60 epochs). The loop size of 30 km to 50 km shows a high variation of VRS coordinates due to the fact that most of points in this 30 km to 50 km loop were located in urban areas and the observing environment was less ideal comparing to other loops. To achieve high reliable performance from Thai-NRTK GNSS solutions for the cadastral survey in Thailand, it is recommended that the reference receivers spacing should be kept within 50 km. because the ambiguity-fixing is 100% successful. The variation of VRS coordinates is still inconsistent with the short period of the observed time (See Figure 7); therefore, the total Thai-NRTK GNSS solution time should be observed longer than 2 minutes.

5. Concluding Remarks

This research aims to investigate the performance of Thai-NRTK GNSS for the cadastral survey in Thailand. The solution performances of Thai-NRTK GNSS in VRS mode are tested using the real fieldwork observations in real environment with the large number of test points (2,122 test points). All CORS loops (143 loops) are separated into four loop categories comprising of 30 km to 50 km, 50 km to 70 km, 70 km to 90 km and 90 km to 110 km, respectively. This study concludes that the Thai-NRTK GNSS positioning technique is well suited for the cadastral survey in Thailand. Generally, smaller loop size yields better performance. The ‘rate of ambiguity-fixing’ was 100% successful only for loop size of 30 km to 50 km. Thus, to achieve the high reliable performances from Thai-NRTK GNSS solutions for the cadastral survey in Thailand, it is recommended to keep the reference receivers spacing less than 50 km and to keep the observation time longer than 2 minutes.

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