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Article

Accuracy Verification of a Smartphone-Based PPK GNSS Surveying Technique and Earth Volume Determinations

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Abstract. Raw global navigation satellite system (GNSS) measurements from a smartphone are used for position determinations as they can be extracted from the Android operating systems together with Thailand Department of Lands (DOL) provide network real-time kinematic GNSS correction services; hence, enabling cheaper and more compact for high precision solutions. This study applies the GNSS raw observations obtained from a smartphone in order to determine positions and later compute an Earth volume based on obtained positioning results as Thailand constructions are increasing in different scales and earthworks is one of the primary works. The experimental area is 11,145 square meters with 21 ground markers. GNSS signals are measured every 1 second at 1-hour observation period. Computed observations from a smartphone provide relatively optimal horizontal and vertical positioning accuracies of 4 and 8 centimetres with the longest convergence time of 40 minutes. Differences between the determined Earth volumes using the smartphone-based and traditional surveying technique do not exceed 10%. The estimated manhour and equipment cost are efficient can lead to 90% reduction. Performances are demonstrated and assessed on actual earthwork computations. Future work may apply estimated smartphone-based network real-time kinematic (NRTK) and post-processed kinematic (PPK) positioning solutions as ground control points for other earthwork determinations through aerial photography.

Keywords: GNSS smartphone positioning, earthworks, NRTK positioning service.

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1. Introduction

GNSS raw observations from Android devices and ground based network GNSS correction services; network real-time kinematic, are cost-effective solutions to high solution positioning services as providing supports to several applications from positioning, smart agriculture, constructions and navigation. Constructions are rapidly progressing in Thailand but are hamper by the labour shortages caused by the COVID outbreak.

Raw GNSS measurements are logged to a smartphone; Huawei P30, using Geo++ which is one of the commercial application programming interfaces (API), in RINEX format on both L1 and L2 frequencies. Information of the phase centre offset and variations is required for precise carrier phase-based positioning using a smartphone-quality antenna [1]. Precise coordinates are determined by applying real-time corrections generated from the Network-Based Real-Time Kinematic (NRTK) GNSS services maintained by the Department of Lands (DOL). This provides real-time correction services available to registered users across Thailand, utilizing their departmentally maintained widely distributed GNSS Continuously Operating Reference Stations (CORSs) throughout the country [2], [3], [4], [5], [6], [7], [8] and [9].

Applied GNSS positioning algorithms are NRTK positioning; based on carrier-phase relative positioning technique, using generated virtual reference stations (VRS) generate from the DOL centralised data centre and post-processing determination based on the kinematic positioning approach including atmospheric correction models and receiver antenna correction parameters. The focus is on an actual survey engineering works on earthwork volume determinations.

Earthworks are estimated based on the computed coordinates determined using smartphone-based raw GNSS measurements from only L1 frequency data, applying appropriated corrections and models in order to determine precise coordinates.

Two main factors to be considered as they affect the costs are surveying methods and accuracy requirements. Traditional surveying techniques using an electronic theodolite; which are commonly known for time consuming and labour intensive, are also compared to modern surveying method of GNSS positioning technique by using raw measurement data based on single frequency band observations; on GNSS L1 frequency, from a smartphone. Estimated coordinates using raw GNSS dual frequency measurements from a smartphone provide a centimetre level accuracy [10] which are sufficient for earthwork determinations for a land filling project and resulting in surveying cost deduction. The surveyed location, situated in the northern province of Thailand known as Nan, is an open-sky area devoid of ground obstacles. It encompasses a land size of 11,145 square meters.

Precisely coordinates are pre-determined using an electronic theodolite; Pentax ETH-107 through precise angle and direction measurements. Estimated earthworks; smartphone based and traditional methods, are compared and analysed based on their positioning performances.

This work presents precisely estimated coordinate determinations using GNSS observations obtained from a smartphone together with the corrections from DOL's NRTK to simulate one of the practical survey engineering works on earthwork determinations.

2. Test Establishment by a Traditional Surveying Technique

Earthwork computation starts from obtaining land information and determine the scope of the work by conducting a land survey to gather essential information about the project size. Professional surveyors measure the boundaries, topography, existing features, and elevation data of the land for understanding the site and planning the earthworks; hence control points are established before earthwork estimations. Measurements include angle, distances and levelling between defined marks obtained from an electronic theodolite PENTAX ETH-107 [11] and other corresponding measurement equipment required in land surveying that are levelling staff, measuring tape, temporary wooden pegs, hammers, plum, a field survey notebook and surveying teams of at least 4 surveyors.

Ground control points comprised of horizontal and vertical reference coordinates, a temporary ground mark and test points for this earthwork project as described below.

(a) Horizontal coordinates are available from the DOL. Transformed coordinate from local measurement units (Thai measuring systems) is as shown in Table 1.

Table 1. Official land marker point coordinates surveyed by the DOL.

Marker name	Grid coordinates	
	Northing (meter)	Easting (meter)
B1	27344.228	25807.756
B1-2	27346.808	25799.596
B2	27347.560	25789.572
B3	27350.412	25751.508
B4	27347.952	25731.096
B5	27232.104	25708.540
B6	27189.216	25759.364

(b) Vertical referenced coordinate is in a tier 1 category for accuracy determination and located in a well condition and ready to use with available outside the study area; SBM.14041-58 at the latitude of 18.75375°N, longitude of 100.7586 °E and height above mean sea level of 200.428 metres. The marker is located at the Samun bridge, maintained by the Royal Thai Survey Department (RTSD) as shown in Fig. 1 [12].

Fig. 1. Survey vertical ground control marks by RTSD.

(c) Constructed temporary ground marks are established using an electronic theodolite to measure both horizontal and vertical coordinates; east and north, throughout the project site determined by authors' survey members. They are in tier 3 category for accuracy determinations. Distances between the two marker points are less than 60 metres so they are within the line of sight suitable for measuring distances, angles and levelling in the study areas. Two temporary surveyed locations are as shown in Fig. 2. Height differences between points on the ground are measured though levelling method to create a level surface or establish elevation benchmarks (BM). Coordinates are computed through measurement distances between backside and front side of the observers from the known reference point (RP) and BM [13].

Fig. 2. Defined two temporary ground mark locations.

(d) Tested points for height difference measurements are uniformly distributed with a baseline of 25 metres as the tested area is 11,145 square meters; therefore, the number of tested surveyed points in the field is 21 and uniformly distributed as shown in Fig. 3.

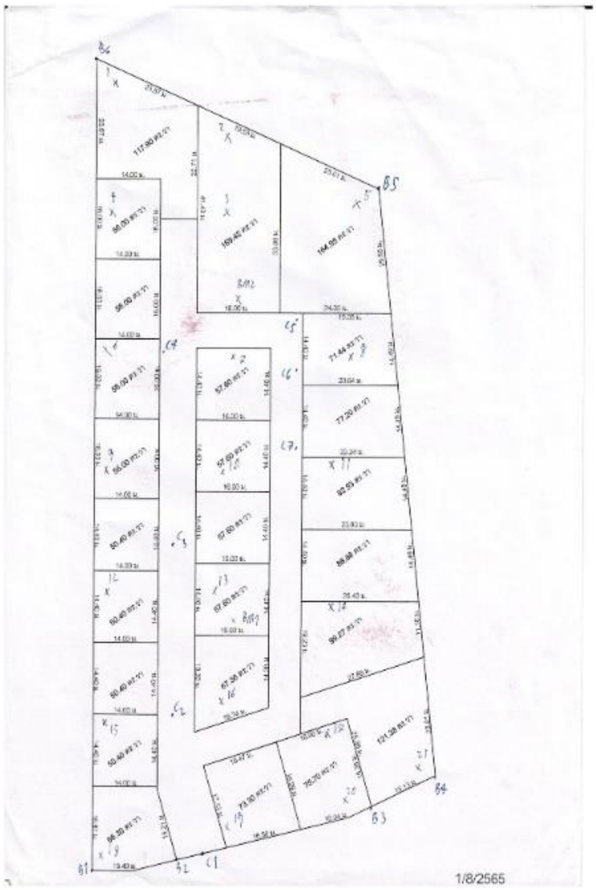

Fig. 3. A sketch with ground marks before performing a field survey.

Survey makers comprise of 2 temporary (yellow), 21 testing (red) and 6 official land marker points (purple) as displayed in Fig. 4 and their corresponding coordinates are in Table 2. The land boundaries are also indicated.

Fig. 4. Temporary ground control and testing points as well as official land marker and boundary.

3. Accuracy Verification of Smartphone PPK Surveying

Today's smartphones contain a built-in GNSS receiver chipset for accurate location-based services. Real-time correction message in RTCM format and raw GNSS measurement data in RINEX format for both observation and navigation data can be retrieved through commercial application programming interface (API) on an Android device.

3.1. Measurement Acquisition

This study applies two APIs: GNSS data logger named Geo++ RINEX logger version 2.1.6 [14] Lefebure NTRIP Client version 2021.12.03 [15] to an experimental smartphone of Huawei P30. GNSS observations include pseudoranges, carrier phase, doppler frequencies and noise parameters from GPS, GLONASS, Galileo, BDS and QZSS for L1, L5, E1B, E1C and E5A supported by the device [1]. Only observations from L1, E1B and E1C are used in this study as GNSS observations from L5 frequency band produces large discrepancies. NRTK positioning corrections based on VRS method are obtained from the DOL in RTCM3 format MSM5.

Table 2. The 21-surveyed test point coordinates and temporary ground control (BM1 and BM2).

Marker name	Grid coordinates		
	Northing (meter)	Easting (meter)	Height (meter)
1	-25765.369	-27192.439	196.100
2	-25744.342	-27208.379	196.081
3	-25750.531	-27222.801	196.278
4	-25769.761	-27216.861	196.409
5	-25721.043	-27228.374	196.200
6	-25771.427	-27243.124	197.559
7	-25756.510	-27250.871	197.760
8	-25731.397	-27254.867	197.443
9	-25781.093	-27264.846	198.599
10	-25761.142	-27270.673	198.634
11	-25737.969	-27277.675	198.656
12	-25786.431	-27286.849	198.730
13	-25766.766	-27290.957	198.708
14	-25744.134	-27299.809	198.644
15	-25795.936	-27320.544	198.740
16	-25772.716	-27316.652	198.666
17	-25747.285	-27329.744	198.716
18	-25802.279	-27342.351	198.627
19	-25778.353	-27342.279	198.783
20	-25746.807	-27339.751	198.692
21	-25736.239	-27340.078	198.649
BM1	-25765.193	-27297.367	198.679
BM2	-25751.373	-27240.832	197.042

Raw GNSS measurement data are later post-processed using RTKLIB software version 2.4.3 b 31 1 [16] in order to obtain estimated coordinates, providing the input data for earthwork simulations in Trimble Business Centre (TBC) commercial software version 5.20 [17].

GNSS dual frequency observations using a smartphone are applied in the land survey for earthworks. NRTK positioning with the VRS correction method provided by the DOL are performed during field surveying. The study area is located at 18.75414 °N and 100.753769 °E as of the surveyed SBM number 14041-58 as shown in the following Fig. 5.

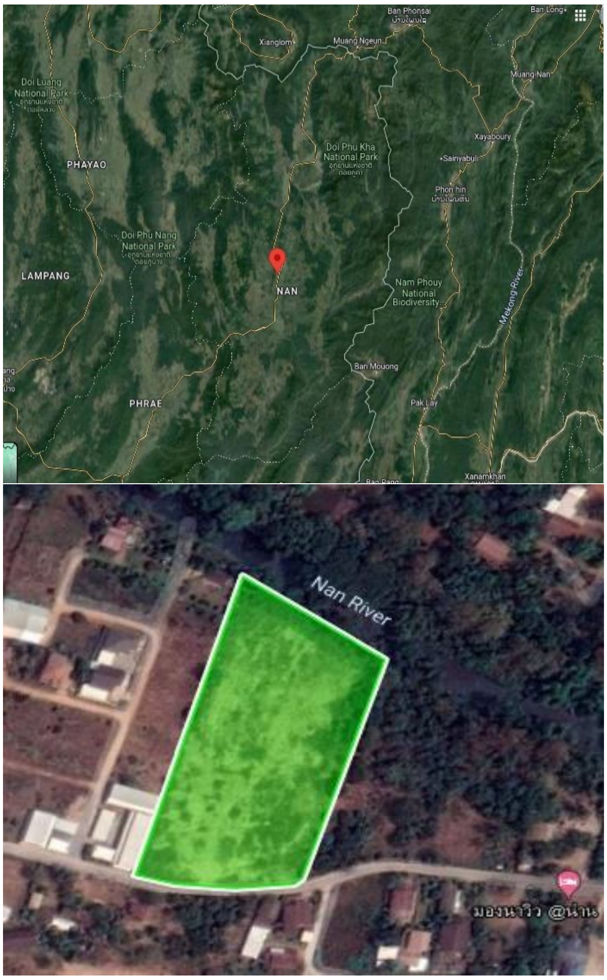

Fig. 5. Experimental area and location in Nan province, Thailand.

3.2. PPK Processing and Accuracy Verification

Smartphone GNSS observations are computed and verified with conventional computations and measurement methods.

3.2.1. Data processing

In a post processing positioning mode, GNSS measurement data are obtained at 1 second interval and the duration of observations is 1 hour in RINEX format; using the mobile phone API. Broadcasted satellite orbit and clock offsets are used; taken from the navigation message. Atmospheric correction models apply empirical models; Saastamoinen for troposphere correction model and broadcasted ionosphere corrections in the obtained satellite navigation message. The smartphone antenna is manually applied in the corrections. Local geoid model is applied to the data processing; Thailand Geoid Model 2017 (TGM2017) [7] and [8]. In RTKLIB settings, the processing mode is set to be kinematic modes for L1 only as the results are significantly varying when the L1 and L5 are simultaneously computed. The settings are as stated in Table 3.

Table 3. Option settings for kinematic single point positioning in RTKPOST.

Options	Settings
Positioning mode	Kinematic
Frequencies	L1
Filter type	Forward
Elevation angle	10 degrees
Ionosphere corrections	Broadcast
Troposphere corrections	Saastamoinen
Satellite ephemeris and clock offsets	Broadcast
Satellite constellations	GPS, GLONASS, Galileo, BeiDou, QZSS
Integer ambiguity resolutions for GPS, Glonass and BeiDou	Continuous, off and off
Solution format	E, N, U Baseline

In real-time positioning mode, correction messages are retrieved in real time from the DOL GNSS NRTK centralised data centre at the rate of 1 second in RTCM format. The L1 antenna phase centre (APC) location for the smartphone used in this experiment is previously determined [18] as shown in Fig. 6. The smartphone is attached on a magnetic mounted on a tribrach as displayed in Fig. 7.

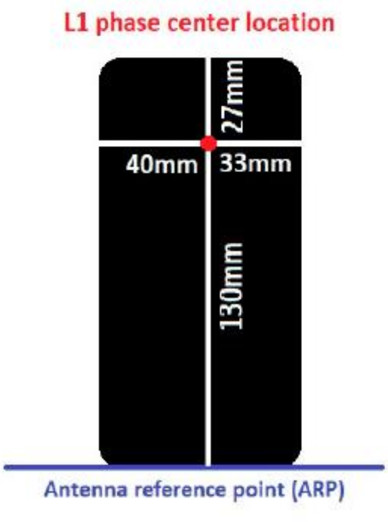

Fig. 6. L1 antenna phase centre location.

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Fig. 7. Smartphone mounting on a tribrach.

3.2.2. Smartphone-based accuracy verification

Computed coordinates in geographical cartesian coordinates, corresponding precisions and convergence time are presented in the Table 4 for the ground marks used in this study. They are determined from GNSS dual frequency measurements by using a smartphone (RINEX and RTCM) using a TBC commercial processing software.

The post processing data in kinematic mode via RTKPOST in RTKLIB showing that the accuracy is at meter level which could not be used for earthworks. Their convergence time is around 40 minutes as of marker point number 15; see Table 4 and Fig. 8.

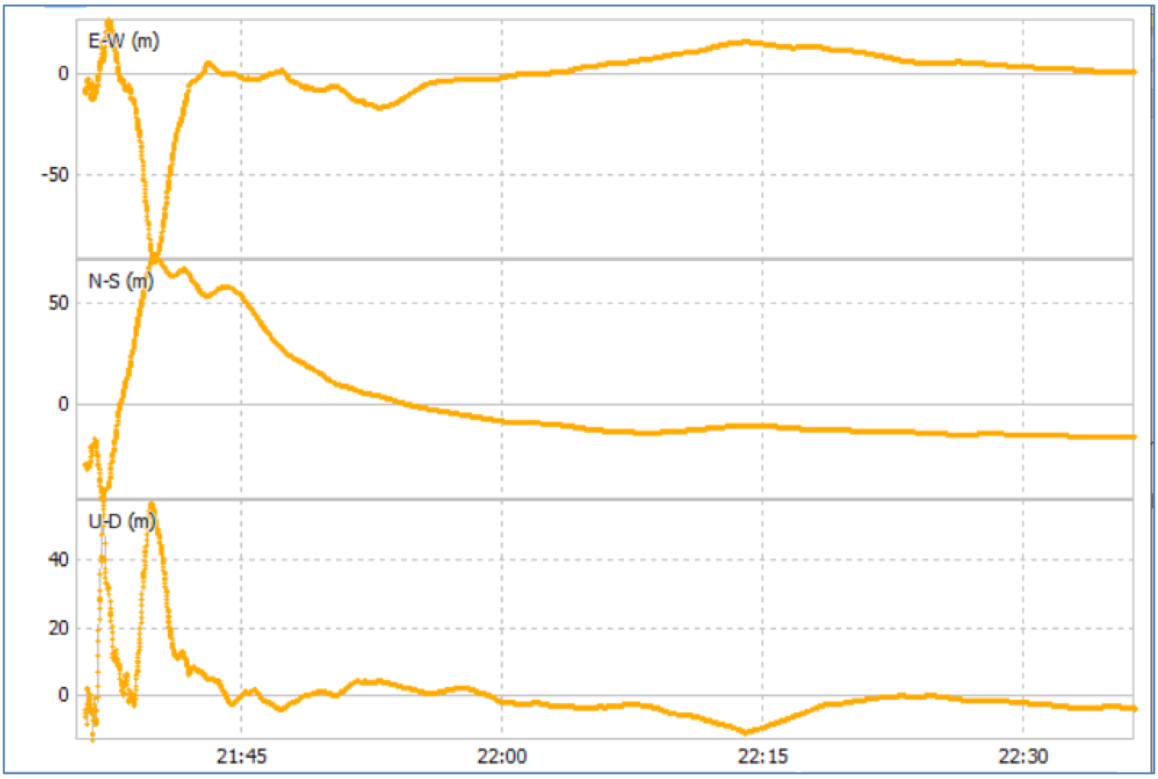

Fig. 8. Post processing in kinematic mode.

Table 4. Computed coordinates using smartphone observations.

Marker name	Easting (meter)	Northing (meter)	Height (meter)	Horizontal Precision (meter)	Vertical Precision (meter)	Convergence Time (minute)
1	684875.803	2074624.512	199.088	1.054	2.332	0
2	684899.085	2074608.312	198.886	0.246	0.397	10
3	684891.114	2074595.006	200.145	0.618	1.914	0
4	684871.861	2074602.019	198.716	0.294	0.632	9
5	684920.523	2074587.764	200.657	0.097	0.202	15
6	684867.986	2074577.088	200.666	1.392	2.150	0
7	684884.516	2074568.158	201.521	0.498	1.022	0
8	684910.874	2074563.713	201.923	1.296	3.217	0
9	684858.017	2074556.978	202.114	0.428	0.636	0
10	684879.690	2074551.348	203.825	0.726	1.582	0
11	684901.737	2074541.199	201.829	0.067	0.111	10
12	684850.999	2074533.644	203.916	0.485	0.780	10
13	684872.047	2074528.480	202.615	0.314	0.587	34
14	684892.386	2074518.135	203.118	0.076	0.152	0
15	684839.818	2074498.994	203.723	0.102	0.204	40
16	684863.185	2074501.652	203.889	0.470	1.104	0
17	684888.989	2074488.513	202.104	0.225	0.605	5
18	684831.553	2074480.262	203.161	0.089	0.299	23
19	684855.569	2074476.272	203.896	1.895	3.863	0
20	684887.293	2074478.912	203.041	0.147	0.217	35
21	684898.421	2074476.492	203.187	0.039	0.079	0
BM1	684873.140	2074522.052	202.653	0.097	0.120	6
BM2	684889.961	2074575.165	201.850	0.122	0.199	0

4. A Potential Application of Smartphone Surveying Technique

Earthwork computation is processed using the TBC commercial software based on two widely used steps starting from coordinate method and averaged end area method to determine the areas and volumes respectively.

Computed earthworks based on traditional measurements with electronic theodolite and smartphone-based GNSS measurement are presented in Table 5 showing that the differences are 9.7 percent which is less than the accuracy requirement of 10 percent. Desired height after land filling is 199.148 metres.

Table 5. Comparisons of computed earthwork volumes between traditional and GNSS survey.

Volumes from surface geometry	Traditional survey	GNSS survey
Material below	11,330.7 m^3	10,229.8 m^3
Differences m^3/%	1,100.9 m^3	9.7%

On smartphone-based verification, computed coordinates using the TBC software based on GNSS observations from a smartphone and traditional surveying measurements using an electronic theodolite are compared in order to determine the average differences in geographical cartesian coordinates; in easting, northing and height above mean sea level. Their averaged differences are -0.319 metres easting, -0.322 metres northing and 0.037 metres in height component. Computed accuracy from the smartphone-based GNSS observations and corrections from the NRTK positioning services is at decimetre level; therefore, the measurements and the method proposed in this study can be applied for earthwork. It is noted that only L1 signals are applied in the data processing, data without outliers are used in the computations. Positioning solutions have to be converted relative to the predefined temporary control points located in the surveyed area before computing the positioning accuracy differences between the two methods. This work applies Helmert/conformal transformation. Computed coordinates are used for earthwork determinations. GNSS observations have been collected in the evening because of the heat throughout the day, resulting in smartphone's failure to work for the full hour of observations and sometime causing convergence times of up to 40 minutes before reaching steady positioning solutions.

5. Conclusions and Recommendations

This study applies an GNSS single frequency; L1, observation from a smartphone; Huawei P30 and ground-based station corrections provided from the NRTK positioning services based on VRS approach provided by the DOL. Precisely determined ground control points in both horizontal and vertical coordinates are officially retrieved from both the RTSD and DOL including 6 ground land markers and 1 vertical control point where 2 temporary ground marks and 21 test points are established at the study area. Conventional levelling has been performed to establish measuring height from the first order defined point of the national vertical datum to the defined point; BM1 which is later used to measure the geodetic height for another temporary ground marks and test points. Precisely estimated coordinates based on smartphone's GNSS observations are applied in real-world practical engineering works on earthwork computations which are traditionally determined with an electronic theodolite; for example, PENTAX ETH-107 to achieve accuracy requirements at assigned criterions.

This modern surveying using the GNSS dual frequency smartphone mounting to the tribrach. Observation epoch is at 1 second and interval of 1 hour. Total measurement durations are 5 days during the night as the heat during the day stops smartphone from working. Data are post-processed in kinematic mode using the RTKLIB software in order to obtain the coordinates. Real-time corrections are obtained and used in the post-processing by converting them to the observation files using the RTKCOV in RTKLIB to convert RTCM to RINEX format. The preliminary results showing that the dual frequency measurements; L1 and L5 bands, from a smartphone produce a positioning error of at a metre-level hence they cannot be used for earthworks determinations. Only L1 measurements are further applied in the estimations. Local geoid model; TGM2017, are applied to determine the height above mean sea level. Computed coordinated are in geographical cartesian coordinates and UTM systems and for the studied area in Nan, it is UTM 47N. Estimated horizontal and vertical positioning accuracies are 4 and 8 centimetres respectively. Some observation data needs relatively a long convergence time of up to 40 minutes. It is noted that the coordinate transformation to UTM 47N applies a Helmert conformal transformation. The offsets are at the earth-centre origin; translation and rotation about the axis. The commonly used transformation method is Affine transformation where the translation, rotation and scaling are considered.

Estimated surveyed coordinates generate the earthwork simulations in contour and surface slicer model. The required height after earthwork completion is at 199.148 metres and needed to meet the required accuracy is within ±10 percent [19]. Computed earthwork volumes are 11,330.7 cubic metres with coordinates determined from electronic theodolite and 10,229.8 cubic metres using the GNSS observations from a smartphone; the difference is 9.7 percent. In terms of manhour and equipment costs, the conventional surveying method cost around 10,000 THB; around 285 USD, whilst modern method is around 1,000 THB or 28.5 USD. This study concludes that the GNSS observations from smartphone and corrections from the NRTK positioning services along with appropriate data processing allows the computed coordinates for earthwork determinations. Further improvements might be implemented based on results from this work as listed below.

- More experiments using different types of smartphones and low-cost receivers as well as making measurements in different environments in order to validate both method and results.
- Try to use the second frequency in the smartphone by including further information or model as well as including extension antenna to the smartphone.
- Heat protection to smartphones especially in a high temperature weather condition.
- Precisely determined coordinates can be applied as ground-controlled points (GCP) for aerial photogrammetry-based earthwork computations.
- Use of an external antenna to improve the GNSS signal reception ([20],[21])

References

[1] C. Netthonglang, T. Thongtan, and C. Satirapod, "GNSS precise positioning determinations using smartphones," in *2019 IEEE Asia Pacific Conference on Circuits and Systems (APCCAS)*, Bangkok, Thailand, 2019, pp. 401-404, doi: 10.1109/APCCAS47518.2019.8953132.

[2] T. Charoenkalunyuta, C. Satirapod, V. Keitniyomrung, and P. Yomwan, "Performance of network-based RTK GNSS for the cadastral survey in Thailand," *International Journal of Geoinformatics*, vol. 15, no. 3, pp. 13-19, 2019. [Online]. Available: https://doi.org/10.52939/ijg.v15i3.1847

[3] C. Rizos and C. Satirapod, "Contribution of GNSS CORS infrastructure to the mission of modern geodesy and status of GNSS CORS in Thailand," *Engineering Journal*, vol. 15, no. 1, pp. 25-42, Dec. 2010.

[4] T. Jongrujinan and C. Satirapod, "Stochastic modelling for VRS network-based GNSS RTK with residual interpolation uncertainty," *Journal of Applied Geodesy*, vol. 14, no. 3, pp. 317-325, 2020. [Online]. Available: https://doi.org/10.1515/jag-2020-0007

[5] S. Kriengkraiwasin, C. Charoenphon, K. Butwong, V. Kovitpongkajorn, P. Yomwan, T. Thongtan, and C. Satirapod, "Unification of GNSS CORS coordinates in Thailand," *Survey Review*, vol. 54, no. 387, pp. 1-9, 2022. [Online]. Available: https://doi.org/10.1080/00396265.2021.1987002

[6] T. Thongtan, S. Sawatdiaree, and C. Satirapod, "GNSS time and frequency transfers through

national positioning, navigation and timing infrastructure," *Journal of Applied Geodesy*, vol. 16, no. 2, pp. 123-130, 2022. [Online]. Available: https://doi.org/10.1515/jag-2021-0061

[7] P. Dumrongchai, C. Srimanee, N. Duangdee, and J. Bairaksa, "The determination of Thailand Geoid Model 2017 (TGM2017) from airborne and terrestrial gravimetry," *Terrestrial, Atmospheric and Oceanic Sciences*, vol. 32, no. 5, pp. 857-872, 2021. [Online]. Available: https://doi.org/10.3319/TAO.2021.08.23.01

[8] P. Dumrongchai, T. Buatong, C. Satirapod, and S. Yun, "Improved height determination using a correction surface by combining GNSS/leveling co-points and Thailand Geoid Model 2017," *Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography*, vol. 40, no. 4, pp. 305-313, 2022. [Online]. Available: https://doi.org/10.7848/ksgpc.2022.40.4.305

[9] P. Dumrongchai, J. Patsadutarn, and C. Satirapod, "Performance tests of geodetic receivers with tilt sensors in obstructed environments using the NRTK GNSS technique," *Journal of Applied Geodesy*, vol. 17, no. 1, pp. 39-52, 2023. [Online]. Available: https://doi.org/10.1515/jag-2022-0047

[10] L. Wanninger and A. Hesselbarth, "GNSS code and carrier phase observations of a Huawei P30 smartphone: Quality assessment and centimeter-accurate positioning," *GPS Solutions*, vol. 24, no. 2, 2020, doi:10.1007/s10291-020-00978-z.

[11] Asahi Precision, *Pentax Electronic Theodolite ETH-105A/107/107C/110C/110F/120C/120F Instruction Manual*, 1998.

[12] Royal Thai Survey Department. "Horizontal Control Point Networks." Accessed: 3 July 2023. [Online]. Available: https://gnss-portal.rtsd.mi.th

[13] Department of Water Resources, "Surveying for design water body conservation projects," Department of Water Resources, Bangkok, Thailand, 2011.

[14] L. Design. "Google Play, Lefebure NTRIP Client." [Online]. Available: https://play.google.com/store/apps/details?id=com.lefebure.ntripclient&hl=en_US

[15] GEO++, "Google Play, Geo++ RINEX Logger." [Online]. Available: https://play.google.com/store/apps/details?id=de.geopp.rinexlogger

[16] T. Takasu, *RTKLIB ver. 2.4.2 Manual*. 2013. [Online]. Available: https://www.rtklib.com/prog/manual_2.4.2.pdf

[17] Trimble, *Trimble Business Center Manual*. 2021. [Online]. Available: https://mytrimbleprotected.com/knowledge/docushare/retrieve?handle=File-503698

[18] M. Uradzinski and M. Bakula, "Assessment of static positioning accuracy using low-cost smartphone GPS devices for geodetic survey points' determination and monitoring," *Applied Sciences*, vol. 10, no. 15, 2020, doi:10.3390/app10155308.

[19] The Community Development Department, *Improving the Procedure Operating Manual*. The Community Development Department, Bangkok, Thailand, 2021.

[20] B. Li, W. Miao, G. Chen, et al., "Ambiguity resolution for smartphone GNSS precise positioning: Effect factors and performance," *J. Geod.*, vol. 96, no. 63, 2022. [Online]. Available: https://doi.org/10.1007/s00190-022-01652-7

[21] M. Li, Z. Lei, W. Li, K. Jiang, T. Huang, J. Zheng, and Q. Zhao, "Performance evaluation of single-frequency precise point positioning and its use in the Android smartphone," *Remote Sens.*, vol. 13, p. 4894. 2021. [Online]. Available: https://doi.org/10.3390/rs13234894

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