Application of an Integrated Survey Approach for Urban Cadastral System

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Abstract

The global land institutions have increasingly recognized the need to work towards practical, integrated, and scalable implementation of alternative methods to cadastral surveying. Cadastral surveying is a land management and land administration tool to provide a safe and reliable real property registration system. In this regard, an integrated survey is one of the alternatives that combine Differential GPS and Total Station to be used as a single instrument, called SmartStation. The aim of the study is to investigate the accuracy/precision, and time expenditure among Differential GPS, Total Station and Smart-Station. To investigate this objective, both primary and secondary data were collected and analyzed through mixed approach. The study benchmarked a network consisted of nine control points that were selected purposely to avoid satellite obstructions. The reference network was established by Total Station to be served as a reference (true value) for the test of Smart-Station and GPS-RTK. To increase accuracy and reliability of the reference network, control points were measured with two-face measurements. Accordingly, the precision of reference network is 9.4mm which is acceptable according to the tolerance value estimated. Based on this, accuracy, and time expenditure of the three methods were tested on all control points. A confidence level of 95% was used to ascertain reliability of the measurements. Despite a few differences, the result shows that accuracy of all measured points fall within the confidence level. Hence, an integrated survey approach was obtained to be better in terms of the stated criteria/indicators – accuracy, and time expenditure. SmartStation combines the best of both. Hence, SmartStation can save an enormous amount of time, speed up work, reduce costs and increase profits Therefore, we recommend decision makers and practitioners to use SmartStation approach for the fact that SmartStation approach has the following advantages – no long traverses needed, less set ups needed, two people are sufficient, takes less time, and provides uniform and higher accuracy.

Keywords: Accuracy; Precision; Integrated Survey; DGPS; Total Station; SmartStation

1. Introduction

The global land community has increasingly recognized the need to work towards practical, coordinated integration and scalable implementation of alternative approaches to land administration system, ones that better serve the interests of the majority of groups in society (Hendriks et al., 2019). A land administration system provides a country with the infrastructure to implement land related policies and land management strategies. The United Nations and organizations such as the International Federation of Surveyors (FIG) have for many years' undertaken studies to understand and describe land administration systems and particularly the cadastral component (Williamson and Ting, 2001). Cadastral system, which is a land management and land administration tool, provides a safe and reliable real property registration system. Cadastral systems system can no longer rely on manual processes or traditional structures that supported individual surveying methods in the past (Chekole, 2014). Stand alone or isolated approaches that supported individual tasks where data and processes were maintained separately, such as GPS and total station, are not efficient and sustainable (Williamson and Ting, 2001). Thus, in order to make the system efficient and sustainable, there should be alternative solution for the better implementation of cadastral system. The contemporary technologies have brought efficient approaches to cadastral system such as integrated survey – SmartStation, using high resolution satellite images, Drone technology that can produce ortho-rectified aerial photographs, Mobile applications, and so forth. With these technologically advanced approaches, the systems of cadaster have been improving from time to time. One of such approaches is SmartStation technology, which is emerging as a good alternative for collecting spatial data. According to Doskocz (2023) the approach should be considered to establish control points and detailed points.

As described in the FIG Statement on the Cadastre (FIG, 1995), cadastre is defined as: A parcel based and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, and ownership or control of those interests, and often the value of the parcel and its improvements. It may be established for fiscal purposes (e.g. valuation and equitable taxation), legal purposes (conveyancing), to assist in the management of land and land use (e.g. for planning and other administrative purposes), and enables sustainable development and environmental protection. The FIG statement explains that future cadastres would develop modern cadastral infrastructures that facilitate efficient land and property markets, protect the land rights of all, and support long term sustainable development and land management. Furthermore, facilitate the planning and development of national cadastral infrastructures so that they may fully service the escalating needs of greatly increased urban populations (UN-FIG, 1996).

According to the proclamation No: 818/2014 (FDRE, 2014), the Ethiopian government has issued and approved Urban Landholding Registration which has to be implemented throughout the country (Chekole et al., 2020c). In order to accomplish the required task, aerial photo and

Ground Control Point (GCP) have been taken by Information Network Security Agency (INSA) and Ethiopian Mapping Agency (EMA) respectively. With regard to the ground surveying, a standard called Urban Legal Cadastre No. 03/2015 (MUDI, 2015) was issued to establish a data standard for cadastral surveying and mapping (Chekole, 2014). Ground surveying has many applications with better accuracy, among which Differential Global Positioning Systems (DGPS) and total station have become more and more important for land administration and management tasks. The use of total station and GPS has been in use since their introduction. However, they are not flexible in the spatial data capture to provide for varying use. In addition to this, the costs of the respective instruments are unaffordable. In this regard, practitioners in the area have introduced an approach called SmartStation. SmartStation is an approach whereby high performance total station is merged with a powerful GNSS receiver to act as a single instrument. With SmartStation there is no need to search for and set up over control points, to run long traverses, or to resect the position as the case in conventional total station. One can measure to points and objects that can never be occupied with an RTK receiver. Total stations need local control points over which they can be set up, from which they can traverse, and to which they can measure to resect their positions. On the other hand, GPS RTK receivers can determine their positions within a few seconds to centimeter-level accuracy using data from GPS reference stations that may be 50km or more away. GPS RTK rover receivers are fast and efficient to use but need an open view of the sky in order that they can receive the satellite signals. They are at their most advantageous in wide, open areas. 1 By contrast, total stations can measure and stakeout where RTK cannot be used: to building corners, to points under trees and bushes, in city canyons, on construction sites where there are large obstructions (Leica Geosystem, 2005). Total stations and GPS RTK equipment each have their advantages. SmartStation combines the best of both. Hence, SmartStation can save an enormous amount of time, speed up work, reduce costs and increase profits (Doskocz, 2023).

Ethiopia has been facing many challenges on the issues of cadastral system due to the absence of a systematized land file management and digital cadastral information. Cadastral information is collected through cadastral surveying, which is the discipline of land surveying that relates to the definition or re-establishment of land parcel boundaries. Cadastral surveying involves interpreting and advising on: boundary locations, the status of land, and. the rights, restrictions and interests in property. The classical cadastral system approaches are no longer adequate to support sustainable land administration system (Chekole et al., 2020b). On the basis of this, the study was motivated by a methodological gap, i.e. lack of previous practical experience on the use of SmartStation. Cognizant to this, Bahir Dar city, one of the largest cities in Ethiopia is selected since it has an inefficient cadastral system. The city did not keep an up-to-date digital cadastral maps (World Bank, 2016; Chekole et al., 2020c; Chekole, 2020a; Chekole et al., 2020b, 2021b; Chekole, 2021a). Cadastral map is a digital form of land records that show all the boundaries of different parts of land pieces. Cadastral maps are not an end in themselves, but together with the cadastral register, their support land administration systems.

2. Objective and Scope of the Study

The primary objective of this study is to investigate the performance of a SmartStation approach for urban cadastre. Specifically, the study intends to investigate and evaluate the accuracy and precision of an integrated survey and individual surveying methods. In addition, it is aimed to compare time expenditure between integrated survey and individual surveying method. Thematically, the study is limited within evaluating the accuracy/precision, and time expenditure of an integrated survey versus individual surveying approaches.

3. Research Method and Materials

To achieve this research, primary and secondary sources of data have been used. Primary data were collected from Total station and DGPS measurements. An experimental research method was used in order to evaluate the performance of an integrated survey approach. Based on this, the researchers have established a network of traverse points as a reference (true value) for the rest of measurements. Total station and differential GPS have been used to take the required measurement. The first method, which is an integrated survey, was performed by mounting differential GPS on the top of the total station so as to take the required measurement simultaneously. The second method was performed using total station and DGPS separately on the same point. Next, data has been processed in Leica Geo Office (LGO) and Arc GIS. LGO software was used to adjust the baseline between CORS and reference control points, and to adjust the traverse network. Arc GIS was used to map the accuracy and precision. Data has been analyzed using qualitative and quantitative methods of analyses. The data collected from primary data source were analyzed quantitatively. And then results have been evaluated and compared in order to ascertain which method has improved the accuracy, precision and time expenditure.

For the sake of eliminating or at least reducing errors stemming from collimation axis error, vertical axis error, compensator errors (longitudinal and transverse), vertical index errors, two face measurements with two rounds were taken. Mean values of the two face measurements used in case if there is differences. Furthermore, the reference network was adjusted first with free adjustment in order to eliminate any contradictions in the fixed points. The traverse checked for gross errors by:

$$\epsilon = K.\sqrt{n} \qquad \text{Eq. 1}$$

Where, $\in$ referes the error emerging from the traverse

K distance in kilo meter from one station to the next

n is the number of stations

The 2D quality (Q_{xy}) of measurements can be computed using the formula below:

$$Q_{xy} = \sqrt{\sigma_x^2 + \sigma_y^2} \qquad \text{Eq. 4}$$

Where: σ_i is standard deviation of X, and Y coordinates

In most cases gross errors may happen in a measurement and therefore the accuracy of the measurement needs to be checked in order to avoid the gross errors. There is a lot of accuracy checking mechanisms, for instance, through two face measurement, adjustment, etc. Using these mechanisms, gross errors can be detected (Csanyi and Toth, 2007).

The collected data have been validated with least square adjustment. As a matter of human limitations, imperfect instruments, unfavorable physical conditions and improper measurement routines, which together define the measurement condition, all measurement results most likely contain errors. To reduce the measurement errors on the final results one need to improve the overall condition of the measurement using least square adjustment (Fan, 2000a, 2000b ;). Least square adjustment is a method of estimating values from a set of observations by minimizing the sum of the squares of the differences between the observations and the values to be found.

$$\sum_{i=1}^{n} P_i \varepsilon_i^2 = minimum \qquad \text{Eq. 2}$$

$$P = \begin{bmatrix} p_1 & 0 & 0 \\ 0 & p_2 & 0 \\ 0 & 0 & p_n \end{bmatrix} = diag(P_1, P_2, \ldots P_n) \qquad \text{Eq. 3}$$

Where p_i: weight of i^{th} measurement

ε: residual vector and

n : number of observations

<u>Evaluation of Standard Deviation (Precision)</u>: standard deviation is a measure of variations of the repeated measurement, i.e. of the precision of each individual observation. It can be computed from the mean values of the individual measurement and the individual measurement. Standard deviation is computed using the following formula.

$$SD(l) = \sqrt{\sum_{i=1}^{n} \frac{(\bar{l}-l_i)^2}{n-1}} \text{ , } \bar{l} = \sum_{i=1}^{n} \frac{l_i}{n} \qquad \text{Eq. 5}$$

<u>Evaluation of RMSE (Accuracy)</u>: RMS (Root Mean Square Error) is a measure of accuracy of the individual measurement. It can be computed from the deviations between true and measured values. True value of the measured quantity is the value which was determined with significantly higher precision. In this project the coordinates of the reference network were considered as 'true' which is determined in 1mm level. RMSE was computed using the following formula:

$$RMSE(l) = \sqrt{\sum_{i=1}^{n} \frac{(\hat{l}-l_i)^2}{n}} \qquad \text{Eq. 6}$$

Where: $\hat{l}$ is the established value, l_i is individual measurement and n is the number of measurements.

In addition to the standard deviation and root mean square error, there is a term called misclosure error in surveying. Misclosure error is the situation where the last in a series of linked traverse lines fails to join up exactly with the first. It is calculated by $e = \sqrt{\sum D^2 + \sum L^2}$, where D is departure and L is latitude of the traverse leg.

4. Results and Discussions

Global Navigation Satellite Systems (GNSS) and Total stations methods are generally used to establish both horizontal and vertical control network points. The conventional total stations need local control points over which they can be set up, from which they can traverse, and to which they can measure to resect their positions. On the other hand, GPS RTK receivers can determine their positions within a few seconds to centimeter-level accuracy using data from GPS reference stations that may be 50km or more away. GPS RTK rover receivers are fast and efficient to use but need an open view of the sky in order that they can receive the satellite signals. They are at their most advantageous in wide, open areas. By contrast, total stations can measure and stakeout where RTK cannot be used: to building corners, to points under trees and bushes, in city canyons, on construction sites where there are large obstructions. Total stations and GPS RTK equipment each have their advantages. SmartStation combines the best of both. The release of SmartStation from Leica Geosystems marked a significant step in making integrated GPS and total station technology commercially available (Leica Geosystem, 2005; Craig, 2008). SmartStation technique is an approach whereby high performance total station is combined with a powerful GNSS receiver to act as both GPS and total station simultaneously. The integrated GPS and total station technology removes the need for traversing to propagate coordinates from distant control points by providing RTK GPS positioning of the total station (Craig, 2008). Integrated GPS and total station systems significantly improve the efficiency of surveyors, are easy-to-use and provide a cost effective entry point to RTK GPS technology (Leica Geosystem, 2005). With SmartStation there is no need to search for and set up over control points, to run long traverses, or to resect the position.

Appreciating the introduction of the SmartStation technology, different measurements with different instruments were taken for accuracy, precision, and time expenditure comparisons. Accordingly, all results from surveying measurements are analyzed, interpreted, and presented separately in separate tables. Results from Total Station (hereafter, TPS), DGPS and SmartStations (hereafter, SS) are computed with their respective standard deviations. Results of the time expenditure of the three measurement methods are also presented. Finally, all results analyzed and comparisons are made among the three measurement methods.

Two control points of the reference network were observed with static measurement for three hours. In order to transform the observed points from WGS-84 to Adindan Ethiopia coordinate system, first a baseline was processed from TANA[1] CORS (Continuously Operating Reference Station) that provides Global Navigation Satellite System (GNSS) to the measured two control points. CORS facilities collect and record, in an automated manner, the GPS data at a known location that are required for relative positioning (Snay and Soler, 2008; Madani et al., 2016). In our study, we used TANA CORS as a reference for the establishment of two control points. After processing the baselines, the global coordinate system was changed in to the local coordinate system. Those coordinates were used as known benchmark for the measurement of the reference network. The positional accuracy of these two points is below 0.3mm level as indicated in the Table 4.1.

Table 4.1: GPS Post-processed bench mark coordinates

Point Id	Easting (m)	Northing (m)	Posn. Qlty (m)
TANA-CORS	317707.4662	1279229.2407	0.0000
W02	322139.6307	1282366.7622	0.0003
W03	322079.6685	1282366.5387	0.0003

4.1. Total Station Measurement Result

A total station is a theodolite with an integrated distance meter that can measure angles and distances simultaneously. The typical analyses of various methods of surveying are based on differences of coordinates. In the presented analyses, the coordinates produced using static GNSS surveys were stated as references. For the sake of evaluating an integrated survey approach – the SmartStation – a network consisting of 9 points established with total station as a reference value. These points were measured repeatedly to provide better precision of the network.

Table 4.2 Established value of the Network by Total Station

Mean values of the total station (TPS)					
Point Id	**Easting** (e)	**Northing** (n)	σ_e	σ_n	**2D Quality**
1	322138.2334	1282404.8011	0.0005	0.0006	0.0008
2	322139.6305	1282366.7624	0.0006	0.0007	0.0009
3	322079.6688	1282366.5379	0.0003	0.0009	0.0009
5	321996.8328	1282364.6333	0.0003	0.0005	0.0006
6	322026.2430	1282418.5889	0.0004	0.0002	0.0004
8	322063.4369	1282459.0101	0.0005	0.0002	0.0005
10	322094.2464	1282460.1901	0.0008	0.0005	0.0009
11	322124.3974	1282459.1297	0.0002	0.0011	0.0011
12	322138.8711	1282452.0206	0.0002	0.0009	0.0009
		Misclosure Error	0.0004	0.0006	0.0094

[1] TANA CORS is a network of stations that provide GNSS data consisting of carrier phase and code range measurements in support of 3D positioning, meteorology, space weather, and geophysical applications. The geographical location of TANA is found in Bahir Dar University, Bahir Dar, Ethiopia. The raw data can be accessed from https://igs.bkg.bund.de/ with the name TANA00ETH.

Mean values of these points were used as a reference for evaluating and comparing the SmartStation technology. Since surveying measurements are not free from errors, it is recommended that averaging the repeated measurements to reduce the errors thereof. This averaged value is then considered as established value – true value of the measurement. Benchmarking this value, accuracy of other measurements is compared with reference to the established value.

As indicated in table 4.2 below, the positional quality of the network is expressed in terms of standard deviation. The closing error (Misclosure Error) for the traverse is calculated to be 9.4mm. To ensure that whether this numerical value is acceptable of not, a standard called Urban Legal Cadastre (MUI, 2015) was used as a reference. According to this standard, linear misclosure allowed for second-order[2] traverse must be below 1:15,000 relative error. This value is dependent on misclosure and the distance covered by the traverse legs. The total perimeter of the traverse is 420m. Thus, dividing the misclosure error to the total distance of the traverse gives approaching 1:44,500, which is less than the standard. In this regard, it can be said that the measurement is acceptable with tolerable measurement errors.

4.2. Real-Time Kinematic RTK GPS Measurement Result

Real Time Kinematics (RTK) measurement is a relative surveying technique, where two GNSS antennas measure their position relative to each other in real time (Ghilani and Wolf, 2015). RTK measurement referenced directly from TANA CORS has been taken in order to compare the results with SmartStation approach. In this case, the base reference is zero order control point which is the CORS – assumed to be zero error in GPS measurements. A CORS – Continuously Operating Reference Station – is a GNSS[3] reference station that provides continuous and permanent real-time positioning information for a specific area. Below table is presented the results of RTK measurement referencing the CORS.

[2] A second order control point refers to a survey control points that can be used to position detail points referencing first order control points.

[3] Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location. By definition, GNSS provides global coverage.

Table 4.3 Real Time Kinematics (RTK) DGPS result

Point Id	**RTK**			
	Easting (e)	**Northing (n)**	**2D quality**	
			σ_e	σ_n
1	322138.1856	1282404.7970	0.0054	0.0042
2	322139.6744	1282366.7263	0.0055	0.0052
3	322079.6640	1282366.4936	0.0072	0.0065
5	321996.8137	1282364.6487	0.0071	0.0069
6	322026.2056	1282418.5208	0.0121	0.0147
8	322063.4448	1282458.9966	0.0054	0.0044
10	322094.2443	1282460.1735	0.0040	0.0032
11	322124.3635	1282459.1156	0.0060	0.0070
12	322138.8518	1282452.0170	0.0070	0.0048

The RTK measurement was performed to compare quality of the measurement with that of the Total Station measurement. In addition to this, it is intended to compare the RTK result with SmartStation measurements.

Following this, the coordinate differences between RTK and TPS – the reference coordinate – was calculated (see Table 4.4). A maximum difference in X coordinate was 4.7 cm and Y coordinate is 6.8 cm. A minimum difference in X coordinate was 2.1 cm while Y coordinate 0.36 cm. In order to measure accuracy of the RTK measurement, RMSE was calculated using Equation 6, which is 4.27 cm.

Table 4.4 Coordinate differences and RMSE of RTK

Point No	TPS		RTK		Residuals (TPS-RTK)		Residual^2	
	Easting	Northing	Easting	Northing	Rx	Ry	Rx^2	Ry^2
1	322138.2334	1282404.8011	322138.1856	1282404.7970	0.0478	0.0041	0.0023	0.0000
2	322139.6305	1282366.7624	322139.6744	1282366.7263	-0.0439	0.0361	0.0019	0.0013
3	322079.6688	1282366.5379	322079.6640	1282366.4936	0.0048	0.0443	0.0000	0.0020
5	321996.8328	1282364.6333	321996.8137	1282364.6487	0.0191	-0.0154	0.0004	0.0002
6	322026.2430	1282418.5889	322026.2056	1282418.5208	0.0374	0.0681	0.0014	0.0046
8	322063.4369	1282459.0101	322063.4448	1282458.9966	-0.0079	0.0135	0.0001	0.0002
10	322094.2464	1282460.1901	322094.2443	1282460.1735	0.0021	0.0166	0.0000	0.0003
11	322124.3974	1282459.1297	322124.3635	1282459.1156	0.0339	0.0141	0.0011	0.0002
12	322138.8711	1282452.0206	322138.8518	1282452.0170	0.0193	0.0036	0.0004	0.0000
						RMSE	0.0290	0.0313
							RMSE	0.0427

4.3. SmartStation Result

A SmartStation is a unique, high performance total station that perfectly integrates a powerful GNSS receiver. Simply set up the SmartStation and let GNSS determine the position of the total station. With SmartStation no need to worry about control points, traverses and resections. Just set up wherever it's convenient. Within a few seconds, RTK determines the position to centimetre accuracy at ranges up to 50 km from a reference station. This approach helps to work in the shortest possible time – simply fix the position with GNSS and then survey with the total station.

Table 4.5 Results of the SmartStation approach

	SmartStation (SS) Coordinate		2D quality	
Point Id	**Eating (e)**	**Northing (n)**	σ_e	σ_n
1	322138.1934	1282404.7841	0.0075	0.0065
2	322139.6464	1282366.7651	0.0050	0.0046
3	322079.6816	1282366.5378	0.0050	0.0048
5	321996.8629	1282364.6332	0.0048	0.0061
6	322026.2443	1282418.5720	0.0050	0.0068
8	322063.4573	1282458.9970	0.0078	0.0086
10	322094.2394	1282460.1653	0.0063	0.0057
11	322124.3864	1282459.1057	0.0073	0.0100
12	322138.8614	1282452.0007	0.0067	0.0049

As the result showed, the misclosure error is about 8.3 mm and the error emanated from the measurement is 2.5 cm from the true value. When comparing this value with that of RTK measurement, there is 1.27 cm error difference. This means accuracy of SmartStation measurement is much better that that of RTK measurement.

Table 4.6 The differences in coordinates between the established value and SmartStation

Point No	$Total\ Station\ (TPS)$		$SmartStation\ (SS)$		$Residual\ (TPS - SS)$		$Residuals^2$	
	E	N	E	N	Rx	Ry	Rx^2	Ry^2
1	322138.2334	1282404.8011	322138.1934	1282404.7841	0.0400	0.0170	0.0016	0.0003
2	322139.6305	1282366.7624	322139.6464	1282366.7651	-0.0159	-0.0027	0.0003	0.0000
3	322079.6688	1282366.5379	322079.6816	1282366.5378	-0.0128	0.0001	0.0002	0.0000
5	321996.8328	1282364.6333	321996.8629	1282364.6332	-0.0301	0.0001	0.0009	0.0000
6	322026.2430	1282418.5889	322026.2443	1282418.5720	-0.0013	0.0169	0.0000	0.0003
8	322063.4369	1282459.0101	322063.4573	1282458.9970	-0.0204	0.0131	0.0004	0.0002
10	322094.2464	1282460.1901	322094.2394	1282460.1653	0.0070	0.0248	0.0000	0.0006
11	322124.3974	1282459.1297	322124.3864	1282459.1057	0.0110	0.0240	0.0001	0.0006
12	322138.8711	1282452.0206	322138.8614	1282452.0007	0.0097	0.0199	0.0001	0.0004
						RMSE	0.0200	0.0161
							RMSE	**0.0257**

In order to assure the reliability of the measurement, it was verified through confidence level. Since the number of measurement is small, t-distribution was used to compute the confidence interval. T-distribution is a type of probability distribution that resembles normal distribution but for smaller sample size. Using 95% confidence level and 5% risk level, the measurement has been verified.

The difference between the true and measured values theoretically should be zero, which is the center of the t-distribution graph. To calculate the upper and lower interval limit, constant k could be computed from confidence level and degree of freedom. Since the number of measurements is n=9, degree of freedom will be n-1, which is 8. And k was computed in excel using the function [tinv(0.05,8)] with confidence level of 95%. k=2.306
Thus, the confidence interval limit is:

$$0 \pm k\sigma_{d_{(SS-TPS)_i}}$$

Where: $\sigma_{d_{(TLS-TPS)_i}}$, is the sigma difference between TPS and TLS
k: constant
$\pm$: +, for the upper limit and -, for the lower limit intervals

The confidence interval for the difference between total station (TPS) and real time kinematics (RTK) calculated as:

$$d_{(RTK-TPS)_i} = P_{TPS_i} - P_{RTK_i}$$

$$\sigma_{d_{(RTK-TPS)_i}} = \sqrt{\sigma^2_{TPS_i} + \sigma^2_{RTK_i}}$$

$$d_{(RTK-TPS)_i} < k\sigma_{d_{(RTK-TPS)_i}}$$

So, the confidence interval is:

$$0 \pm k\sigma_{d_{(RTK-TPS)_i}}$$

Where; $d_{(TPS-RTK)_i}$ =difference between TPS and RTK coordinates, *i* = (N, E) coordinates
$\sigma_{d_{(RTK-TPS)_i}}$ = sigma, standard deviation of $d_{(TPS-RTK)_i}$

Table 4.6 presents the confidence interval for the difference between coordinates of RTK and TPS. Since the theoretical difference between their coordinates is zero, the confidence interval is $[-\mathrm{k}\sigma_i, +\mathrm{k}\sigma_i]$, where k is t-score value calculated from confidence level, 95% and degree of freedom (k=2.306). Depending on this requirement, 95% of the points should lay inside this confidence interval limit.

Based on the results obtained from RTK measurement, the difference between coordinates of TPS and RTK, and The difference between standard deviations (sigma) of TPS and RTK showed that RTK measurement has been laid within the allowable confidence limit. There is no any measurement of the network rejected.

Table 4.7 Confidence interval limits and coordinates difference between Total Station and RTK

Point Id	Standard deviation (TPS)		Standard deviation (RTK)		$k.\delta_d$(TPS-RTK)		|TPS-RTK|	
	E	**N**	**E**	**N**	**E**	**N**	**E**	**N**
1	0.0005	0.0006	0.0054	0.0042	0.0261	0.0191	0.0478	0.0041
2	0.0006	0.0007	0.0055	0.0052	0.0261	0.0240	0.0439	0.0361
3	0.0003	0.0009	0.0072	0.0065	0.0367	0.0297	0.0048	0.0443
5	0.0003	0.0005	0.0071	0.0069	0.0362	0.0341	0.0191	0.0154
6	0.0004	0.0002	0.0121	0.0147	0.0623	0.0770	0.0374	0.0681
8	0.0005	0.0002	0.0054	0.0044	0.0261	0.0224	0.0079	0.0135
10	0.0008	0.0005	0.0040	0.0032	0.0171	0.0143	0.0021	0.0166
11	0.0002	0.0011	0.0060	0.0070	0.0309	0.0314	0.0339	0.0141
12	0.0002	0.0009	0.0070	0.0048	0.0362	0.0208	0.0193	0.0036

On the other hand, based on the results obtained from SmartStation (SS) measurement, the difference between coordinates of TPS and SS, and The difference between standard deviations (sigma) of TPS and SS showed that SS measurement has been laid within the allowable confidence limit, theoretically which should be the difference in coordinates should not be greater that the difference in standard deviations multiplied by the t score value (in this case 2.306). Thus this measurement proved that, there is no any measurement of the network rejected.

Table 4.8 Confidence interval limits and coordinates difference between Total Station and SS

Point Id	Standard deviation (TPS)		Standard deviation (SS)		$k.\delta_d$(TPS-SS)		|TPS-SS|	
	E	**N**	**E**	**N**	**E**	**N**	**E**	**N**
1	0.0005	0.0006	0.0075	0.0065	0.0371	0.0314	0.0070	0.0059
2	0.0006	0.0007	0.0050	0.0046	0.0233	0.0208	0.0044	0.0039
3	0.0003	0.0009	0.0050	0.0048	0.0249	0.0208	0.0047	0.0039
5	0.0003	0.0005	0.0048	0.0061	0.0240	0.0297	0.0045	0.0056
6	0.0004	0.0002	0.0050	0.0068	0.0244	0.0351	0.0046	0.0066
8	0.0005	0.0002	0.0078	0.0086	0.0387	0.0447	0.0073	0.0084
10	0.0008	0.0005	0.0063	0.0057	0.0293	0.0277	0.0055	0.0052
11	0.0002	0.0011	0.0073	0.0100	0.0378	0.0473	0.0071	0.0089
12	0.0002	0.0009	0.0067	0.0049	0.0346	0.0212	0.0065	0.0040

The traverse has been consisted of 9 points. These points were selected for verification of horizontal position checking in the study area. The position of points on ground is situated in this way (see figure 4.1 and 4.2). As it is indicated in the first figure, the traverse had a closing error of 9.4mm which attributed from all traverse points. But after adjustment, the error has been distributed in all points so that the traverse has adjusted and closed (figure 4.2).

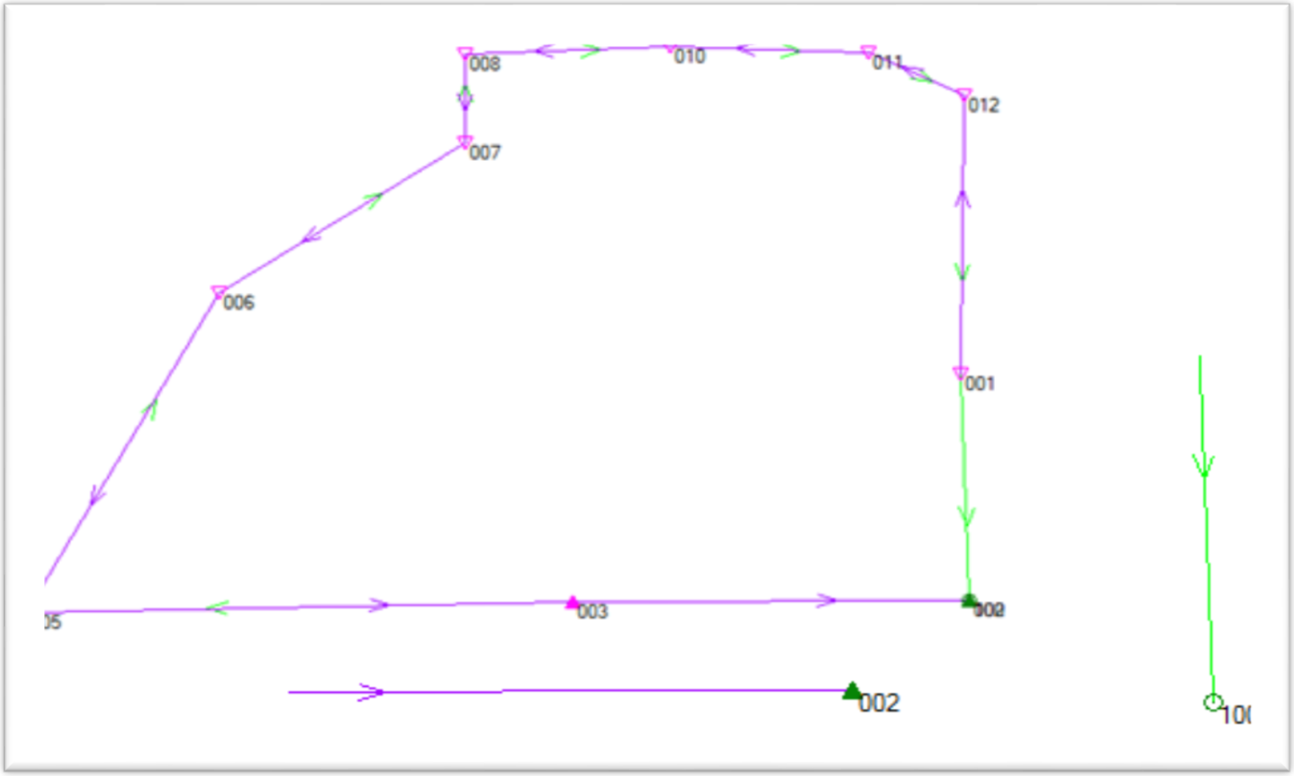

Figure 4.1: Traverse before adjustment

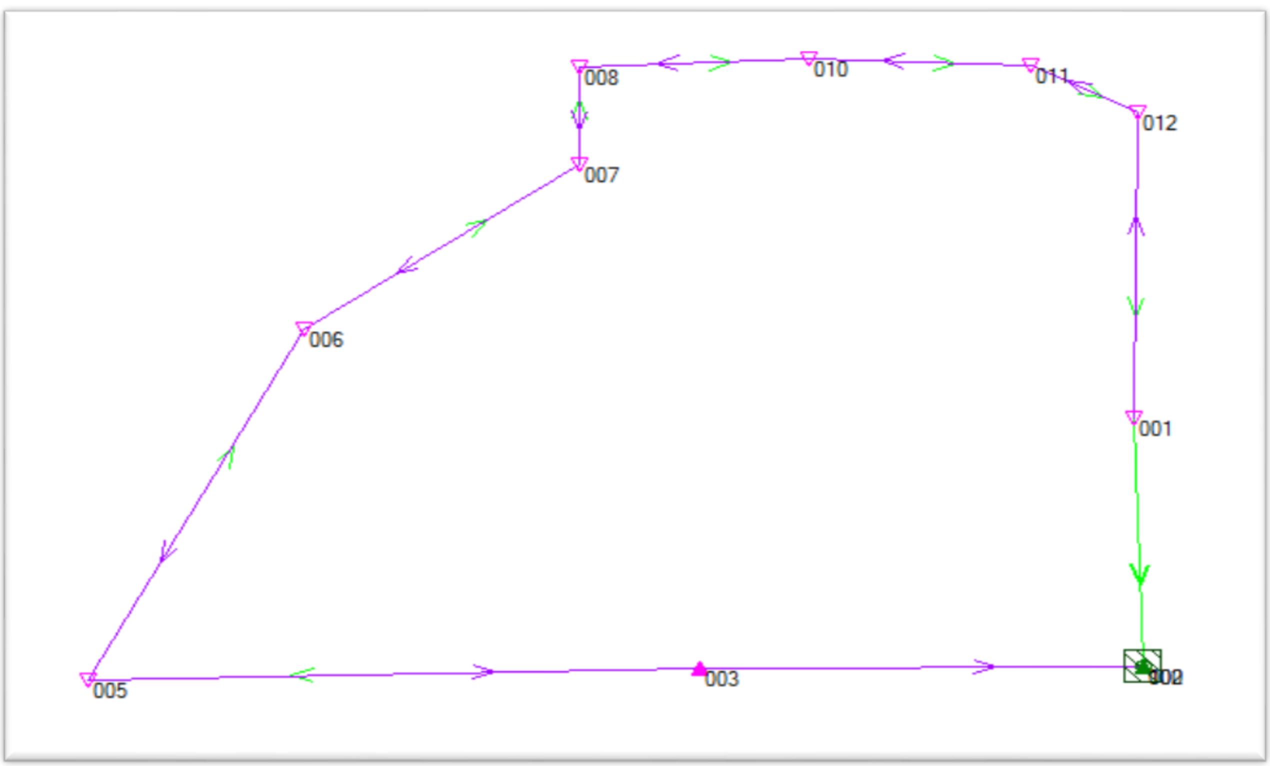

Figure 4.2: Traverse after adjustment

4.4. Time Expenditure of the Approaches

One of the specific objectives of this study was comparing the time required among the three methods. Efficiency of total station, RTK-GPS, and SmartStation approches are affected with their time consumption. So, according to the results obtained, time expended among the three measurement methods are indicated here (see Table 4.9).

Table 4.9 Time Expenditure among the three approaches

Instruments	**Total station**		**DGPS**	**SmartStation**	
Time Expenditure (Minutes)					
Measurement steps	***Instrument***	***Prism***	***Base***	***Instrument***	***Prism***
Setup	4	2	5	5	2
Centering	3	2	3	3	2
Target aiming	---	3	---	---	3
Recording	2	---	2	2	---
Changing station	7	---	8	8	---
Total time expended	16*9	7*9	18*9	18*9	7*9
	144	63	162	162	63
	207 Min		162 Min	225 Min	

As per the results of the study, it was taken 162 minutes to measure all reference points with GPS both for static and RTK measurements. When we see the time expended for total station, 207 minutes were consumed to measure all traverse points, while it takes 225 minutes were expended for SmartStation measurements. This is to mean that to establish the entire points with the use of separated instruments; it took 207 plus 162 which is 369 minute but in the case of the SmartStation way it took only 225 minute. So, there is 144 minute difference between the methods. Hence, using the SmartStation approach saves time that amount 2 hours and 24 minutes.

5. Conclusion and Recommendation

The research deals with evaluation and comparison of accuracy and time expenditure of three surveying methods. These methods are total station (TS), Global positioning system (GPS), and SmartStation (SS). A SmartStation approach is a method by which DGPS and Total Station instruments are combined to be used as a single instrument, called SmartStation. By combining or integrating these instruments many advantages have been gained. Comparing precision, accuracy and the required time of these three measurements will improve the knowledge about how much accuracy and accuracy can be achieved and at what time expense. The study was performed at 9 control points as a pilot area. First reference network consisting of nine points were established by total station as a reference/true value. The precision was acceptable. Next, these established reference control points have been tested by the three methods listed above. In order to ascertain the reliability of the measurement, confidence interval in the form of confidence level and risk level was considered. A confidence level more than 95% was accepted in this regard. The results indicate that accuracy of the three methods is stated through the tables 4.1 to 4.7., time consumption of the three methods also stated in the table 4.8. Besides, in every task of the measurement, time expended was recorded and compared (see Table 4.9) separately for Total Station, DGPS and SmartStation methods. Accordingly, the SmartStation took 225 minutes while the Total Station and DGPS consumed 207 and 162 minutes respectively.

Hence, the result of SmartStation showed that better accuracy (2.74cm) than RTK GPS (3.77cm) with reference to the established network. Thus, in urban areas the researchers recommended to use SmartStation rather DGPS and TPS as isolated instruments. With reference to the time expenditure, the SmartStation way took 225 minute to test the entire points. Whereas, with the separated use of TPS and DGPS took 207 and 162 minute respectively. This is to mean that to establish the entire points with the use of separated instruments; it took 207 plus 162 which is 369 minute but in the case of the SmartStation way it took only 225 minute. So, there is 144 minute difference between the methods.

All in all, total stations need local control points over which they can be set up, from which they can traverse, and to which they can measure to resect their positions. On the other hand, GPS RTK receivers can determine their positions within a few seconds to centimeter-level accuracy using data from GPS reference stations that may be 50km or more away. GPS RTK rover receivers are fast and efficient to use but need an open view of the sky in order that they can receive the satellite signals. They are at their most advantageous in wide, open areas. By contrast, total stations can measure and stakeout where RTK cannot be used: to building corners, to points under trees and bushes, in city canyons, on construction sites where there are large obstructions. Total stations and GPS RTK equipment each have their advantages. SmartStation combines the best of both. With SmartStation there is no need to search for and set up over control points, to run long traverses, or to resect the position. The SmartStation is a unique, high performance total station that perfectly integrates a powerful GNSS receiver. Simply set up the SmartStation and let GNSS determine the position of the total station.

Therefore, the researchers recommend that using SmartStation is more advantageous than using separated instruments – for instance in terms of accuracy, time, cost, and number of professionals to be engaged.

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