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Full Length Research Paper

Wall traverse with GPSSIT and 3D positioning of urban details

Ozsen Corumluoglu

Department of Geomatics, University of Gumushane, Gumushane, Turkey. E-mail: ocorumlu@gmail.com, ocorumlu@hotmail.com. Tel: +90 5553054986.

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In an urban environment, sometimes surveying becomes a very hard task, especially measuring some certain points or details on the ground that are surrounded by obstacles such as trees, fences or buildings. On the other hand, in such areas, survey points installed as references on the ground can easily be lost because of city activities. Wall traverse supported by GPSSIT (GPS Sanal Istasyon Teknigi – GPS Virtual Point Technique) and relying on freely chosen Sanal Istasyon Noktalari (SINs) or – virtual points (VIPs) without worrying about installing any control point on the ground provide a reliable resolution. In this study, establishment of wall traverse points by the support of GPSSIT and TS (GPSSIT and total station) and a detail measurement technique with 3D coordinates using these wall points were introduced and applied in a sample area. As a conclusion, standard deviations were found as m_p = ± 4.53 cm and m_H = ± 3.85 cm in position and height respectively for details.

Key words: Wall traverse, GPSSIT and total station, 3D positioning.

INTRODUCTION

Nowadays even global positioning system (GPS) is commonly in use and even if one of the GPS techniques is chosen for a surveying task in urban environments, it is still required to establish and install some survey points on the ground. But the problem here is that those established stations at appropriate locations especially at the corners of streets can easily and usually be lost in a certain period of time because of excessive city activities performed by city authorities. It sometime becomes very hard and time consuming process to find out those traverse stations that are lost. Even reestablishment of those points becomes most appropriate choice rather than finding them. This type of solution is also subject to the same problem. Therefore, another solution should be considered to overcome the problem fundamentally. The solution suggested here is to establish and install those survey points on side walls of buildings on the streets, especially at the corners in urban environments. During the choice of candidate buildings to be used for the installation of those points which can be called as wall points and can set up a well established wall traverse, the most important factor, which must primarily be taken into consideration, is their consistency to the detail measurement process to be done later on. The second one can be the age and the building usage. It can be suggested that selection priority is given to state and public buildings and then private buildings, but for all those cases, age and strength must be the major priority before all others.

In this technique, these wall points must be specially numbered in a way that anyone can easily recognize and identify it is a wall traverse point. In this number, building address such as street name and door number can be coded. In a detail surveying task, the wall traverse point approach also gives us a chance to register these points to the building owners whose building walls have an installed wall traverse point. This will give some advantages such as prevention from the damage and missing of those points. It can also provide a chance of getting information if something happens or if something is about to happen to those points.

After all, the crucial question here is how these survey points on the walls can be measured in order to produce their 3D coordinates. Another purpose of this paper is to suggest a technique that allows us to use GPS to measure these wall traverse points.

MATERIALS

A low cost GPS surveying technique: GPSSIT and TS

As it is in the aforementioned, today several new application areas which depend on spatial information have been emerging with the impact of new technologies. Usage of spatial data in digital form becomes a common process for such applications. These opportunities make us to review the requirements of information societies and give us a chance to analyze and manipulate data in great extents. Relevant data production techniques then become important issue in terms of speed, format and reliability. Today, most common techniques used in land benefit from total stations or EDMs to produce these kinds of spatial data for details digitally within Cartesian or polar coordinate systems. In such surveying techniques, it is still essential to use reference points established on the ground (Kavanah, 2009). On the other hand, they are still necessary especially due to the application procedures of civil infrastructures or a requirement with respect to current regulations related to surveying procedures in some countries.

Many surveying projects are now implemented by the help of GPS. Therefore, GPS, which is a cutting edge spatial data production technique that depends on satellite observations and is now widely and heavily used all over the world as well as in the developing countries and even in undeveloped countries, has became an important source of revolutionary developments and alterations in surveying discipline and in its application areas since it uses satellites as instantaneous stationary control points moved up into the sky and provides 24 h of spatial data collection advantage to its users at anywhere all over the world and almost without worrying about the weather conditions. GPS supported detail measurement technique are a newly developed detail measurement technique in last two decades and GPS has usually been applied to measure these details directly by using real time kinematic or stop and go GPS measurement techniques (Kavanah, 2009). Although, these sorts of GPS measurement techniques are still in use, in the case of that where details cannot be measured directly by GPS (especially in urban areas), combined systems (GPS+Total Station) have recently been developed to complete surveying. But, the combined systems mean renewal of hardware and also new parts or new devices which are considerably expensive and cost effective. Therefore, they have not been being replaced rapidly and widely into the practice so far. On the other hand, these systems are capable of producing details' GPS coordinates practically a rapid and accurate way.

It is always possible to determine coordinates of the details with respect to some traverse points, which are established on the ground and measured by one of GPS techniques (such as real time kinematic or stop and go), if it is impossible to measure these details directly by GPS (Sumpter and Asher, 1994; Wellenhof et al., 1992). As it is being usual in classical techniques, after the determination of a survey point established on the ground, a total station is set up over this point on a tripod to measure details around. This technique has been being used commonly all over the world and it produces details with accuracy of 2 to 3 cm (Schwarz and Schuberringg, 1992). A technique that promises a similar accuracy and is capable of measuring details without depending on such survey points established to the ground has already been suggested as a previous stage of this study (Corumluoglu and Kalayci, 2007). This technique only requires a low cost GPS receiver set like Ashtech 2000 (which is around $3500). Usage of this technique may be much more viable in developing and third world countries for speeding up their data collection tasks for their map productions in urban environments even in precise and digital format at several scales especially in large scales like 1:1000.

Readers who like to know what GPSSIT and TS is and how it is used for the collection of details in 3D coordinates and without depending on ground-established control points and want further explanations can refer to the previous study of author (Yang and Kim, 1998). GPSSIT with Total Station, which depends on integration of a GPS receiver and a Total Station and lets them to use the same tribrach can also confidentially be used for the measurement of wall points with 3D coordinates. On the other hand, GPSSIT can even be preferred as a detail measurement technique from beginning to the end of a surveying mission if there is not any GPS signal blockage (Kalayci, 2003).

Wall traverse

Underground surveying is an engineering surveying application area that traverse stations are unusually placed. For example, those points are generally located at roof and backs of the underground workings. Therefore, the location of survey points in an underground mine has generally been in the roof or backs of the underground workings. But they present a number of drawbacks for surveyors such that the backs are usually over 5 m above the floor. To eliminate this drawback, they started using an alternative. It includes mounting survey points in the side walls of underground development. Side wall location of survey control would provide accessibility advantages but it needs alternative surveying techniques to transfer position of survey control.

On the other hand, side wall approach for survey control on the ground that can be assumed as a resembling approach to side walls in mines can be a viable alternative for overcoming of some surveying problems seen in an urban environment especially in urban canyons surrounded by buildings. It can be said that obstacles in an urban environment form deep channels like tunnels in mines but without roof. So that, the sight between two consecutive traverse stations become an important issue considering the blockage by this tunnel side walls as being in underground. As it is mentioned above, the survey points are usually set up at roof of tunnels to ease the underground surveying. On the other hand, they are set up on the ground in land surveying. In these two cases, side walls such as tunnel side walls in underground surveying and outside walls of buildings in land surveying can be appropriate locations for these points to establish. This approach promises a solution to overcome some special problems experienced in these two types of surveying application areas.

Land surveying techniques have a great advantage as having an open sky that underground surveying will never have and benefit from GPS. During last 10 - 15 years, GPS satellites covered the sky and now GPS offers great positioning advantages globally to several professional disciplines besides surveying. Even if this is a general expectation from GPS, it has some pitfalls itself because of some signal blockages especially met in urban environment. For such cases, it is crucial to choose a right technique which can overcome this problem without giving any concession in terms of speed, accuracy and easiness.

METHODS

GPSSIT can be a significant technique to prefer instead of using well known classic or GPS surveying techniques. Since it is being a compulsory task to establish survey stations on the ground with respect to the surveying regulations in many countries during lay-out engineering works and even a detail surveying missions, side wall points or wall traverse can also be an appropriate alternative for a surveying task with marked points on side walls of buildings in urban environment instead of setting them on the ground. In wall traverse with GPSSIT, observations can be collected at a distant point which is represented as GPSSIN in order to transfer the coordinates of GPSSIN to wall points (Corumluoglu and Kalayci, 2007; Kalayci, 2003). So that, GPSSIT and TS will be the most appropriate technique for the position transformation from GPSSIN to wall points if advantages of GPS are utilized.

Measurement of wall points

Although, GPSSIT itself is a viable method to fulfill a surveying task

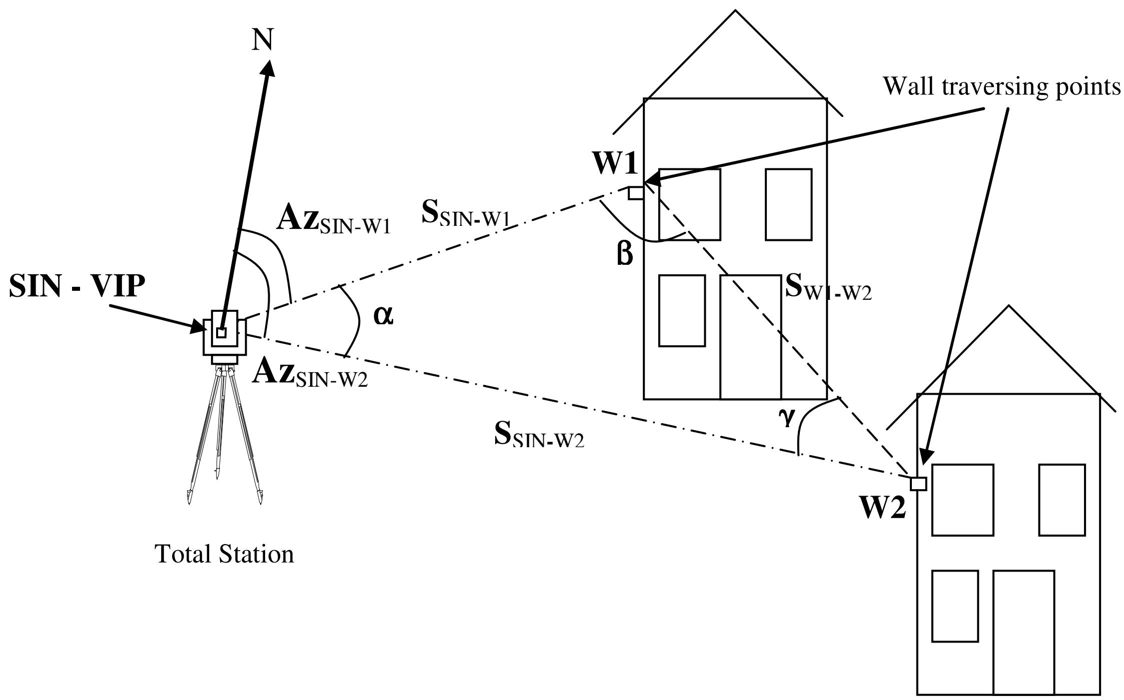

Figure 1. Determination of SIN (VIP) by wall traverse technique.

beginning to end, traverse with established stations can still be a compulsory task when GPS signal blockages happen in an urban environment. In this case, as it is suggested here, instead of traverse with ground based established references, the use of sidewall based and established references so wall traverse can be a promising approach which can be employed efficiently, feasibly and compatibly, otherwise it means too much consideration on losses of ground based references especially in cities.

GPS can be used for positioning of wall points at the time of highest GPS satellite constellation in a mission day and there are also some procedures to follow up, If GPSSIT and TS is chosen as a surveying technique for the measurement of wall points in 3D coordinates. Total station and GPS antenna must be coaxial. Therefore these devices must be leveled to coincide their vertical axes passing through GPS antenna phase and total station optic centers along the same plumb line. To fulfill this requirement, GPSSIT and TS uses TeT (Tek Triblak – single tribrach) combination technique which it has been well explained in the previous work [4]. TeT combination technique used with GPSSIT and TS supports that GPS receiver and a Total Station work consistently for the measurement of wall points. On the other hand, the coordinates of GPSSINs first must be produced in geographic coordinates and projected to optical center of total station along the geoids normal. Thus, they can be transformed to Cartesian system. Distances and angles to wall points at the optical center can then be referred to right coordinates transferred from GPSSIN (GPS Sanal Istasyon Noktasi – GPS VIrtual Point) in interest. Coordinates of GPSSIN where total station is set up at are fundamentally determined by GPS observations using TeT.

As first step of a wall traverse, for benefiting from double difference GPS observations, one of the two GPS receivers is set up over a GPS reference point whose coordinates are known (Kavanah, 2009). Then, the wall traverse by GPSSIT and TS is started at the most appropriate site where it does not cause any problem to GPS signals and at the most appropriate time in a day. After choosing the appropriate site, measurement procedures for the coordinate transfer from GPSSINs to wall points can be followed as those explained for detail measurements by GPSSIT and TS technique in the previous study (Corumluoglu and Kalayci, 2007). As a final step, coordinates of wall points determined in GPS coordinate system must be transformed into a regional local coordinate system for 3D coordinate requirement with orthometric heights.

Detail measurements by wall traverse

As it can be seen from Figure 1, during detail measurement in 2D by wall traverse, first, it is required to determine SIN (Sanal Istasyon Noktasi – VIrtual Point) by transferring the coordinates of wall points (W1 and W2) which are previously measured by GPSSIT and TS. A SIN virtually appears at a freely chosen site that provides proper sight view from SIN to wall points (at least two) and details. For this determination, S_{w1} and S_{w2} distances from SIN to at least two wall points (W1 and W2) and angle β_{W1-W2} between these two wall points at SIN are measured by a total station. During this procedure, horizontal distances from SIN to details and horizontal angles between any one of wall point and each detail are measured by the same total station at SIN. Two wall points are sufficient for collecting 2D coordinate of SINs. After the determination of SIN's coordinates in 2D, 3D coordinates must be computed and transferred to every detail with two step transformations as explained.

In the first step, plane coordinates of SIN as X and Y are solved in two ways. In the second step, height is computed separately by measuring vertical angles to both wall points for increasing the reliability of the determined height. Although, vertical angle and slope distance measurements to only one wall point are sufficient to solve the height of any SIN.

Well known basic sine theorem of a triangle can be used for the computation of plane coordinates of any SIN. In this case, measured horizontal angle (α_{SIN}) at SIN and distances (S_{SIN-W1} and

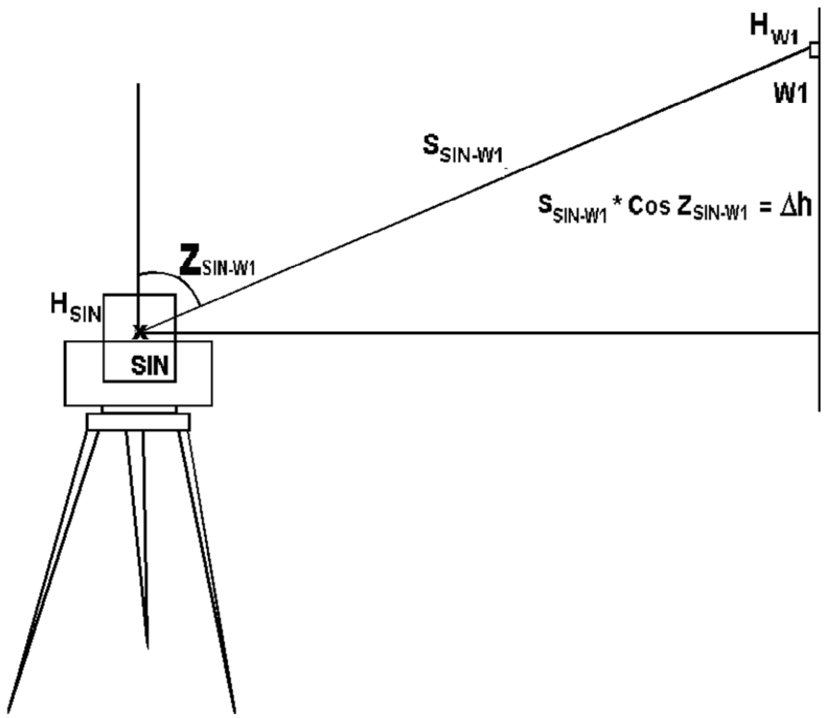

Figure 2. Determination of height of a SIN by the help of wall survey point.

S_{SIN-W2}) to first and second wall points from a SIN are sufficient to determine plane coordinates of the SIN. β and γ denote horizontal angels at the first and the second wall points to the second wall point and to SIN and to the first wall point and to SIN respectively. The sine equation is given in Equations (1 and 2) as:

$$\frac{S_{w1-w2}}{Sin\alpha} = \frac{S_{SIN-w2}}{Sin\beta} = \frac{S_{SIN-w1}}{Sin\gamma} \quad (1)$$

$$Sin\beta = \frac{S_{SIN-w2}}{S_{w1-w2}} Sin\alpha; \quad Sin\gamma = \frac{S_{SIN-w1}}{S_{w1-w2}} Sin\alpha \quad (2)$$

Azimuths at wall points W1 and W2 to SIN are then determined by Equations (3) (Wellenhof (1992)

$$Az_{W1-SIN} = Az_{W1-W2} + \beta \text{ and}$$
$$Az_{W2-SIN} = Az_{W1-W2} + \pi - \gamma \quad (3)$$

The coordinates of SIN can be computed from both wall points in twice by Equations (4 and 5). Then the average is computed by (6).

$$X'_{SIN} = S_{SIN-W1} * Sin (Az_{W1-SIN})$$
$$Y'_{SIN} = S_{SIN-W1} * Cos (Az_{W1-SIN}) \quad (4)$$

$$X''_{SIN} = S_{SIN-W2} * Sin (Az_{W2-SIN})$$
$$Y''_{SIN} = S_{SIN-W2} * Cos (Az_{W2-SIN}) \quad (5)$$

$$X_{SIN} = (X'_{SIN} + X''_{SIN}) . 2$$
$$Y_{SIN} = (Y'_{SIN} + Y''_{SIN}) . 2 \quad (6)$$

This can be called as angle-distance solution. There may be another solution using only measured and computed distances by forming a triangle at the first and second wall points and SIN. After the computation of angle between the first and second wall points at SIN by Equation (7), the same computation procedure can be followed by the help of Equations (1 through 6) above to produce SIN's X and Y coordinates.

$$Cos\ \beta = (S^2_{SIN-W1} + S^2_{SIN-W2} - S^2_{W1-W2}) . (2\ S_{SIN-W1} * S_{SIN-W2}) \quad (7)$$

For SIN's height, zenith angles and distances are measured to both wall points at the relevant SIN and are used in Equations 8 and 9 (Figure 2).

$$H'_{SIN} = H_{W1} - S_{SIN-W1} * Cos\ Z_{SIN-W1}$$
$$H''_{SIN} = H_{W2} - S_{SIN-W2} * Cos\ Z_{SIN-W2} \quad (8)$$

$$H_{SIN} = (H'_{SIN} + H''_{SIN}) . 2 \quad (9)$$

After the determination of SIN's coordinates, details can now be collected by measuring azimuth and distances to details. As can be seen from Figure 3, azimuths to details can easily be computed by Equations (10). When azimuth from SIN to one of two wall points (W1 or W2) is computed using the coordinates of SIN and the wall point preferred, measured angles between first or second wall points and details at SIN can be added to this azimuth to find azimuths to details. Using these detail azimuths and detail distances from SIN, coordinates of details can be computed by Equations (10).

$$X_{Di} = X_{SIN} + S_{SIN-Di} * Sin\ Az_{SIN-Di}$$
$$Y_{Di} = Y_{SIN} + S_{SIN-Di} * Cos\ Az_{SIN-Di} \quad (10)$$

Heights of details can also be determined using a similar Equation (8) after some modifications for details as being in Equation (11). In that case, addition to those horizontal angles and slope distances, zenith angles to details at SIN must be measured too.

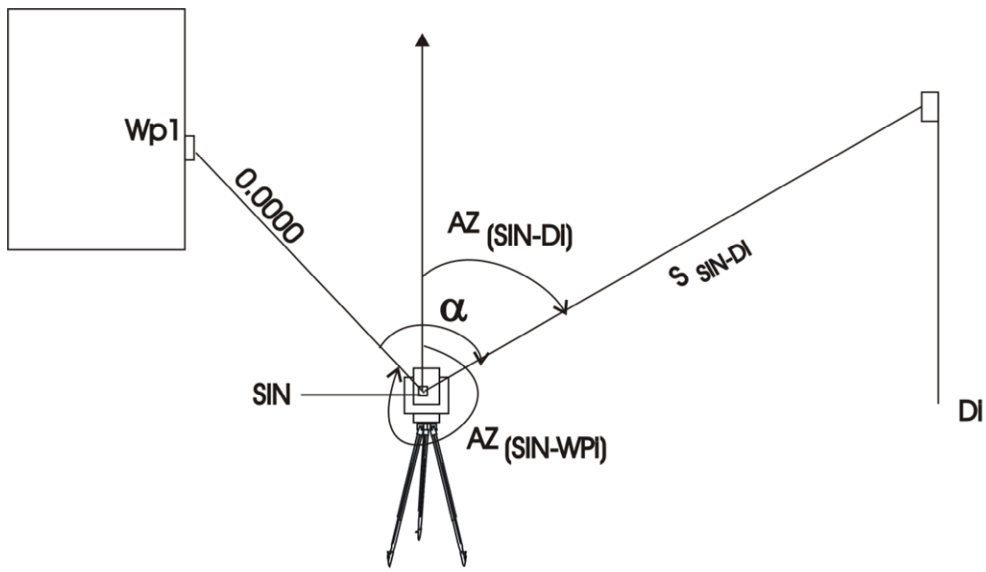

Figure 3. Detail measurement by wall traverse.

$$H_{Di} = H_{SIN} + S_{SIN\text{-}Di} * \cos Z_{SIN\text{-}Di} \quad (11)$$

RESULTS

The case study and the results of the test

An appropriate land part was chosen to test the detail surveying technique based on wall traverse using GPSSIT and TS measurement technique. During the application of these techniques in the test area, a Leica GPS-system 300 SR 9500 dual frequency GPS receiver and a Topcon GTS-701 total station for angle and distance measurements respectively were used at both GPSSINs and SINs. GPS observations and the measurements for the establishment of wall traverse were collected by this GPS receiver in stop and go mode and by the total station with small polyester reflectors used on the wall points respectively and trigonometric measurement technique was used. Another measurement technique used for detail collection was the classic one for the sake of comparison. In the classical measurement section, classic trigonometric measurement procedure for traverse was applied to determine the established control points on the ground by angles and distances and details were then measured with respect to these determined traverse points.

In this study, almost 278 details were measured. After the field operations, the coordinates of details were then computed consequently in twice using the data sets from these two surveying techniques. The coordinate differences (dx and dy) between the coordinates obtained for the same details and from these two different data sets are shown in Figure 4 and height differences in Figure 5.

Measurement analyses

The coordinates for the same details calculated from wall traverse and classic trigonometric detail measurement techniques were compared in term of qualify measure of wall traverse. The results obtained from the application of classical technique were assumed as the true one and the results from wall traverse were then statistically analyzed using Equations 12;

$$V_{X_i} = X_{WT_i} - X_{C_i}, \quad V_{Y_i} = Y_{WT_i} - Y_{C_i}, \quad V_{H_i} = H_{WT_i} - H_{C_i}$$

$$m_X = \pm\sqrt{\frac{V_{X_i} V_{X_i}}{n}}, \quad m_Y = \pm\sqrt{\frac{V_{Y_i} V_{Y_i}}{n}},$$

$$m_H = \pm\sqrt{\frac{V_{H_i} V_{H_i}}{n}} \quad (12)$$

$$m_P = \pm\sqrt{\frac{V_{X_i} V_{X_i} + V_{Y_i} V_{Y_i}}{n}}$$

Where;

m_x : is standard deviation of errors in X coordinate, m_y : is

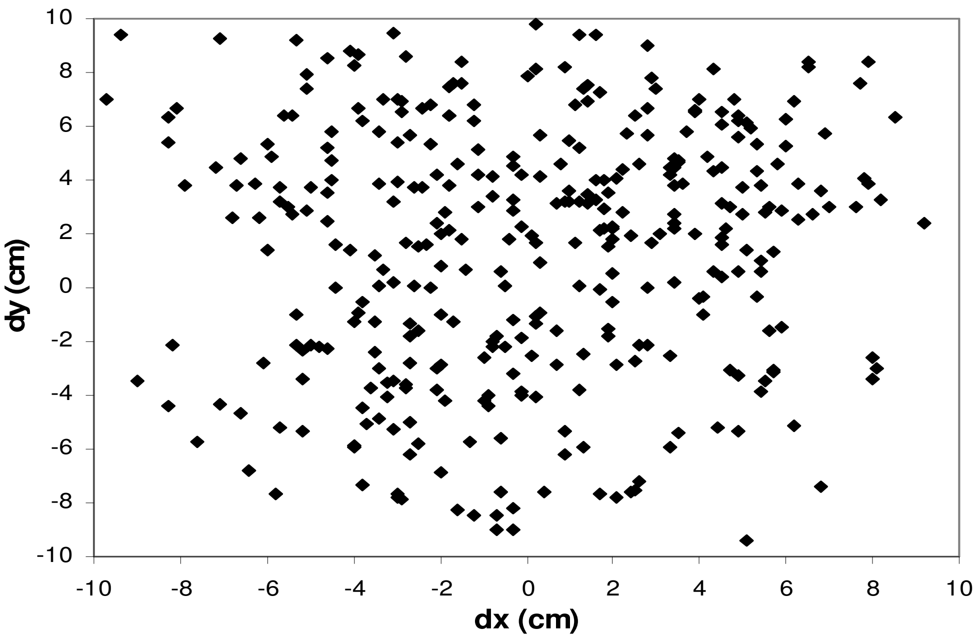

Figure 4. Distribution of differences in coordinates (dx and dy) obtained for the same details with respect to wall and classic traverse techniques.

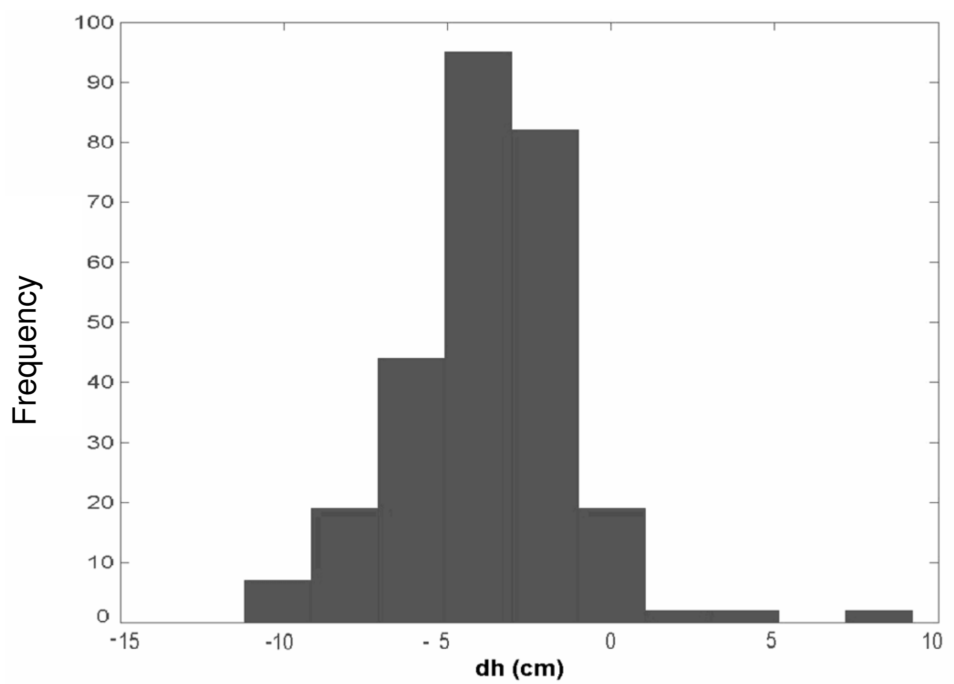

Figure 5. Frequency histogram of differences in heights obtained for the same details with respect to wall and classical traverse techniques.

standard deviation of errors in Y coordinate, m_p : is standard deviation of positioning errors, and n : is number of detail points measured.

Standard deviations of these details have two components one is for positional errors and the other one is for height errors. Position errors are also divided in two as dx and dy. Finally, standard deviations of dx and dy coordinate differences of details with respect to data from two sets were then derived as $m_x = \pm 3.1$ cm, $m_y = \pm 3.3$ cm and the standard deviation of position errors of the details were then obtained as $m_p = \pm 4.53$ cm. Standard deviation of heights is also found as $m_H = \pm 3.85$cm for details.

DISCUSSION

Although, it is a common procedure in classical measurement techniques, GPSSIT and TS detail measurement technique removes the need for stationary point establishment on the ground. But this kind of survey point establishment can still be a requirement in some surveying applications which are being performed with respect to surveying regulations in some countries. As a conclusion of this study, we suggest not to establish these stationary points on the ground but on the wall traverse. Likewise, wall traverse ensures that we set up our measurement devices (such as total station) at anywhere that can provide clear view of details and at least two wall points. In classic traverse, after the installation of stationary survey points on the ground it is usually difficult to find out consecutive ones when a land survey is required later on. In a likewise case, when wall traverse with GPSSIT and TS is used, there would not be such a necessity. So, one advantage of suggested techniques is freely chosen GPSSINs and SINs.

Conclusions

Here it can be stated that the method promises reasonable, reliable and repeatable outcomes for details with respect to the results given in the aforementioned. So that, it can also be said that the method is liable to produce solution, even when general GPS detail measurement techniques such as rapid-static, stop and go, and etc. fail because of the lack of required amount of satellite signals reaching to the GPS receiver. Such situations can happen when some obstacles in the measurement area block GPS signals or even the structural features of details do not allow the collection of proper GPS observations (e.g. corners of a building) at some certain times in a day. There should not be a limitation to complete a wall traverse measurement in such cases since the technique offers SINs and these points can be moved to the most appropriate positions for overcoming sight problem. So that, wall traverse survey points can easily be measured and SINs are positioned.

Wall traverse technique also promises an improved detail measurement system. So, it supports a semi-mobile detail measurement system since SINs can freely be moved to any place. Thus, total station can be set up on a vehicle without unsetting the total station while moving one survey point to another. Measurements can be made faster than even in the cases where sole wall traverse technique is used. Additionally, the power for GPS receiver needed only to position wall points and total station can also be supported by the vehicle power supply after some simple modifications. The system can be safer than as it is being on the ground.

Another advantage of the technique is that the system directly produces heights for the details beside their plane coordinates, since the system uses trigonometric solutions, contrary to the classical technique producing height and position data separately and requiring application of different measurement techniques for height and plane coordinate determination. The measurement system can also be improved with the use of reflectorless EDMs. Finally, it can be said that 3D data can be collected in a more precise and quicker ways with the help of these techniques.

Notations

GPS: Global Positioning System, GPSSIT: GPS Serbest Istasyon Teknigi – GPS Virtual Point Technique, GPSSIT and TS: GPSSIT and Total Station, GPSSIN: GPS Serbest Istasyon Noktasi – GPS VIrtual Point (GPSVIP), SIN: Serbest Istasyon Noktasi – VIrtual Point (VIP), W1 and W2: First and second wall points.

Symbols

α_{SIN}: is measured horizontal angle at SIN between first and second wall points.

S_{SIN-W1}, S_{SIN-W2} and S_{W1-W2}: are distances to first and second wall points from a SIN and between wall points respectively.

β and γ: are horizontal angels at the first and the second wall points to the second wall point and to SIN and to the first wall point and to SIN respectively.

Az_{W1-SIN} and Az_{W2-SIN}: are azimuths at wall points W1 and W2 to a SIN.

X_{SIN} and Y_{SIN} : are SIN's X and Y coordinates.

Z_{SIN-W1} and Z_{SIN-W2}: are zenith angles to both wall points (W1 and W2) at a SIN.

H_{SIN}, H_{W1} and H_{W2}: are heights for SIN, first and second wall points respectively.

S_{SIN-Di}: is distance between SIN and any detail.

Az_{SIN-Di}: is azimuth to a detail at SIN.

X_{Di} and Y_{Di} and H_{Di}: are X and Y coordinates and height of a detail.

Z_{SIN-Di}: is zenith to a detail at SIN.

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