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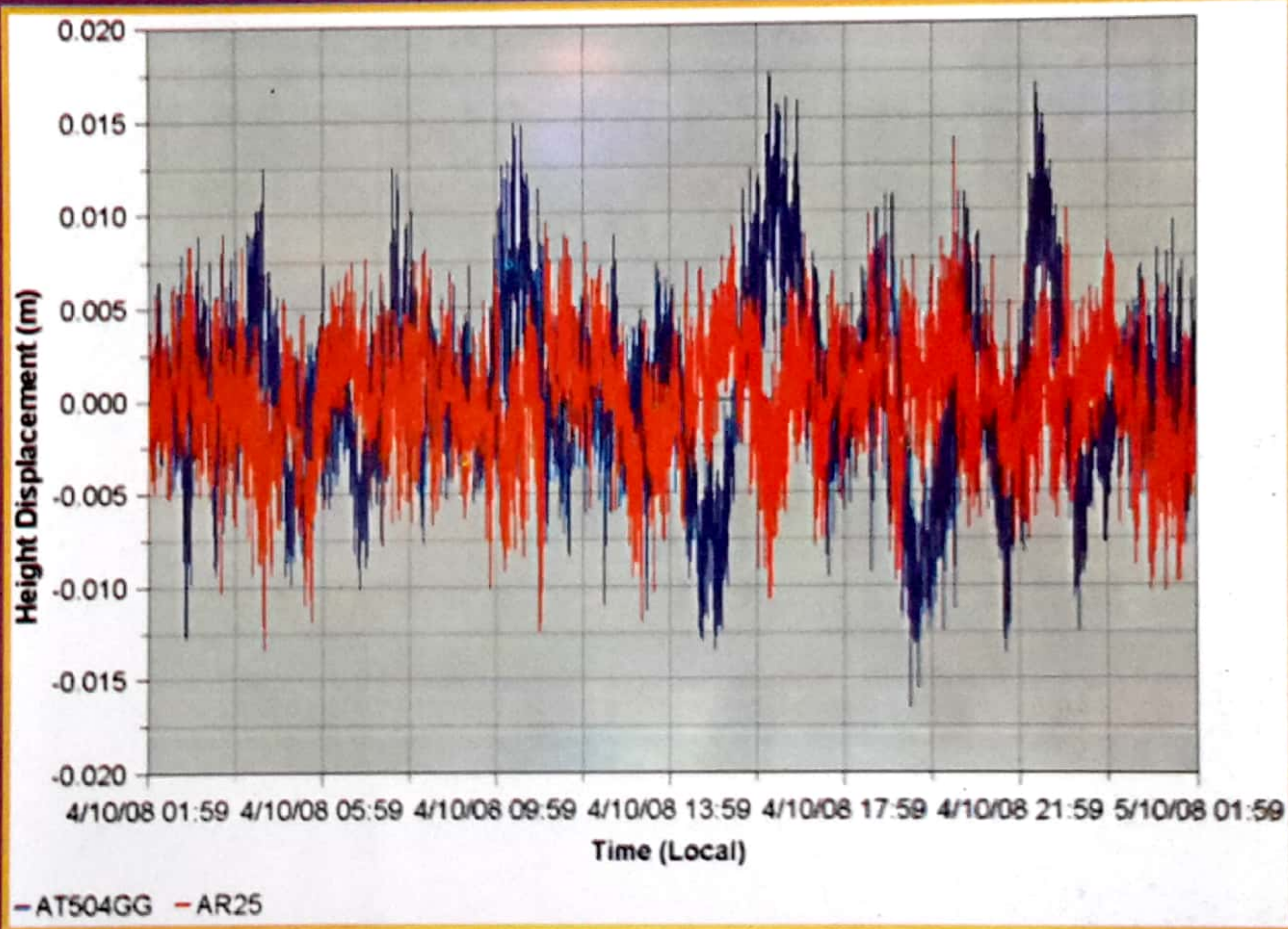

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Double Vectors Analysis of Differential Global Positioning System [DGPS] Data in Static Relative Mode

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Abstract
Static Differential Global Positioning Systems (SDGPS) is a procedure that involves the simultaneous use of two or more code-based receivers. It can provide positional accuracies to within a few centimeters, and thus the method is suitable for higher-order surveying work. In DGPS, one receiver occupies a so-called base station (point whose coordinates are precisely known from previous surveys), and the other receiver or receivers (known as the rover) were set up at stations whose positions are unknown. By placing a receiver on a station of known position, the pseudo range errors in the signal can be determined. Since the base station receiver and rover are relatively close to each other, the pseudo range errors at both the base station and at the rovers will have approximately the same magnitudes. For the purpose of this study, twelve points were selected for observation at Sagamu in Ogun State, Nigeria with a second order control point (H566) within the study area adopted as the base station. Repeated measurements were taken at the rover stations in different observing sessions using a Promak-3 Single Frequency Differential Global Positioning System (SDGPS) and the results compared. The mean square errors for the residuals of each session from the mean were 8.170cm, 8.144cm, 5.044cm, 5.041cm, 11.291cm and 11.291cm respectively for X_1, X_2, Y_1, Y_2, Z_1 and Z_2 respectively. From the results and the analysis, the mean of repeated measurements of the same base using Differential Global Positioning System in a static relative mode was found suitable for higher order geodetic control extension.

Key Words: DGPS, pseudo range, relative positioning, static, session, base and rover, vectors.

1.0 Introduction

Global Positioning System (GPS) as a surveying technology has found wide possibilities of applications, the only restraining factor of GPS being the non-performance of a satellite availability and visibility as well as non-fulfillment of the defined accuracy varied on a character of work (Iżvoltová, 2004). One of such possibilities of GPS use is the use of the static and kinematics GPS mode in control extension for engineering projects, for such precise positioning technique, the Differential Global Positioning System (DGPS) have been widely used.

The global positioning system is based upon observations of signals transmitted from satellite whose orbits are precisely known, transmitting on two microwaves carrier signals (two L-band frequencies). The L1 frequency is 1575.42 MHZ and L2 frequency is 1227.6 MHZ. The L1 carried the navigation message and the SPS code signals while L2 measures the ionospheric delay by PPS equipped receivers; the L1 has a wavelength of 19cm while L2 is about 25cm. The system is a 'one-way' ranging system; i.e signals are transmitted only by satellites and received by the receivers which could give away strategic ground locations. Consequently, the transmitters and receivers must both have accurate clocks in order to resolve distances from the broadcast signal with minimal errors. Since the objective of DGPS surveys is to locate points on the surface of the earth, it is necessary to have a so-called terrestrial frame of reference which enables relating points physically to the earth (Wolf and Ghilani, 2006). The reference used for this is the geocentric reference ellipsoid known as the World Geodetic System 84 (WGS 84) with a rectangular coordinate system (X_e, Y_e, Z_e) superimposed. This three-dimensional rectangular coordinate system has its origin at the centre of mass of the earth. Its X_e - axis passes through the Greenwich meridian in the plane of the equator, its Z_e - axis coincides with the Convectional Terrestrial Pole (CTP) and the Y_e - axis complete a right handed figure. Conversions from geocentric to geodetic coordinates, and vice versa are readily made and are related by the following equations (Wolf and Ghilani, 2006):

$$X_P = (R_{NP} + h_P)\cos\phi_P \cos\lambda_P$$

$$Y_P = (R_{NP} + h_P)\cos\phi_P \sin\lambda_P$$

$$Z_P = [R_{NP}(1 - e^2) + h_P]\sin\phi_P$$

(1)

Where

$$R_{NP} = \frac{a}{\sqrt{1 - e^2 \sin^2\phi_P}} = a(1 - e^2\sin^2\phi_P)^{-\frac{1}{2}}$$

(2)

X_P, Y_P, and Z_P are the geocentric coordinates of any point P, and the term e, which appears in both equations is the eccentricity of the WGS84 reference ellipsoid. Its value is 0.08181919084, R_{NP} is the radius in the prime vertical of the ellipsoid at point P, and a, is the semi-major axis of the ellipsoid and its value is 6378137m (Wellenhof and Moritz, 2005 and Wolf and Ghilani, 2006).

1.1 Statement of Problem

The advent of satellite based positioning techniques, especially Global Positioning System (GPS), which is presently used in a wide range of geodetic and surveying applications, has brought tremendous changes in the processes of precise geodetic control establishment; data acquisition techniques have become more efficient, accuracies greatly improved with new areas of applications opened up hence, simultaneous determination of 3-D positioning referenced to the global (accurately determined) geocentric ellipsoid (WGS 84) has been enhanced. However, Differential Global Positioning System (DGPS) is one of the several methods available for precise positioning in static relative mode, but each of these methods has its peculiarity with regards to behaviour of data acquired. Therefore, this research attempts a double vectors analysis for verification of DGPS data consistency.

1.2 Objectives of the Study

Since the aim of this research is to verify the consistency of DGPS data, the objectives therefore, include:

(i). Acquiring positional data in two sessions per station using a single frequency differential GPS (Promak3) in the study area.

(ii). Using GNSS Solution to process the acquired data.

(iii). Subjecting the processed data to statistical analysis using SPSS 15.0 for windows and Excel spread sheet and draw conclusion.

1.3 Location/ Site of Experiment: The site for this research is located at Sagamu in Ogun State, Southwestern Nigeria. It has coverage of about 5.5km along a profile.

1.4 Justification of Study

The findings of this research shall be of great use in decision making concerning the method of observation to be adopted when using a single frequency differential GPS in relative static mode, especially for higher order control establishment and other engineering applications where the required precision is usually high.

2.0 Methodology

Some of the various field procedures currently used in DGPS surveying include the static relative, rapid static, pseudo kinematics, kinematics, and real-time kinematics methods each of these methods has its peculiarities and advantages (Gerdan, 1992). Therefore, this paper, attempts a double vector analysis of DGPS observed data in a static relative mode so as to carryout a verification of DGPS data consistency.

2.1 Static relative positioning

Static Differential GPS (SDGPS) is a procedure that involves the simultaneous use of two or more code-based receivers. It can provide positional accuracies to within a few centimeters, and thus the method is suitable for certain types of higher-order surveying work (Ruang et al, 2002).

In DGPS, one receiver occupies a so-called base station (point whose coordinates are precisely known from previous surveys), and the other receiver or receivers (known as the rover) were set up at stations whose positions

are unknown. By placing a receiver on a station of known position, the pseudo range errors in the signal can be determined. Since the base station receiver and rover are relatively close to each other, the pseudo range errors at both the base station and at the rovers will have approximately the same magnitudes (Ruang et al, 2002) however, this is not always true when the range widens apart, therefore, longer time of observation at the rover station will be required to properly resolve the errors. After computing the corrections for each visible satellite at the base station, they can be applied to the roving receivers, thus substantially reducing or eliminating some of the following errors: Satellite Clock Error, Satellite Perturbations errors, Ephemeris Error, Ionospheric Refraction, Tropospheric Refraction, Receiver Noise, and Multipath Errors, etc.

2.2 Procedure

Since the desire was to carryout double vectors analysis for verification of single frequency Promarks3 DGPS data consistency, two sessions of observation were made at each station occupied. The principle is as described in section 2.1 above. For each station occupied, each of the two sessions involved a simultaneous observation made consecutively to four or more satellites for a period of 60 minute minimum and 100 minute maximum; depending on the baseline length (Longer baselines require greater observing times). Except for the base, the roving receivers were moved upon completion of the two sessions.

For the purpose of this study, twelve points were selected for observation at Sagamu in Ogun State, Nigeria with a second order control point (H566) within the study area adopted as the base station. As a precaution, the value for the epoch rate in a static survey must be the same for all receivers during the survey; this rate was set to be 5sec for this project, this was done to minimize the number of observations and thus the data storage requirements. All the receivers were connected to controllers that have internal memories as well as SD card for storing the observed data.

2.3 Computational Approach

After all observations were completed, data were transferred to computer for post-processing using GNSS solution Software. As the observation files were downloaded, special attention was paid to station information that is read directly from the file with the field sheets so as to confirm the antenna slant height as a check.

Baseline vectors were computed as changes in X, Y, Z between the base station and the rover stations.

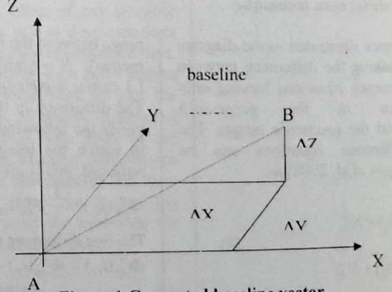

Figure.1 Computed baseline vector

If base station (A) has known coordinates, then the coordinates of rover stations (B) can be computed according to Wolf and Ghilani (2006) as:

$$X_B = X_A + \Delta X$$
$$Y_B = Y_A + \Delta Y \qquad (3)$$
$$Z_B = Z_A + \Delta Z$$

Where (X_A, Y_A, Z_A) are the geocentric coordinates at the base station A, (X_B, Y_B, Z_B) are the unknown station B, while ΔX, ΔY, ΔZ are the computed baseline vector components.

2.3.1 GPS differencing technique (Triple differencing)

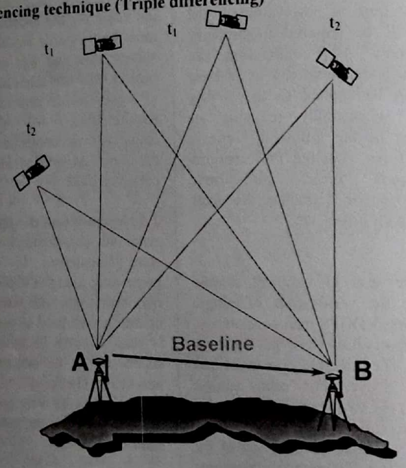

Fig.2.The triple difference technique

The triple difference illustrated in the diagram above involves taking the difference between two double difference equations leaving only the differences in the phase-shift measurements and the geometric ranges. The two double-difference equations can be expressed (Traugott et al, 2008) as:

$$\Phi_{AB}^{jk}(t_1) = \frac{1}{\lambda}\rho_{AB}^{jk}(t_1) + N_{AB}^{jk}$$
$$\Phi_{AB}^{jk}(t_2) = \frac{1}{\lambda}\rho_{AB}^{jk}(t_2) + N_{AB}^{jk} \qquad (4)$$

Where ϕ = Phase shift (or phase difference), t_1, t_2 = Observation epochs, ρ = Geometric range between the receiver and the satellite (in metres), N = Ambiguity (in cycles), λ = The L1 carrier wavelength.

The difference in these two double difference yields the following triple difference equation, in which the integer ambiguities have been removed, this is given as:

$$\Phi_{AB}^{jk}(t_{12}) = \frac{1}{\lambda}\rho_{AB}^{jk}(t_{12}) \qquad (5)$$

The two difference terms are:

$$\Phi_{AB}^{jk}(t_{12}) = \Phi_{AB}^{jk}(t_2) - \Phi_{AB}^{jk}(t_1) \qquad (6)$$

$$\rho_{AB}^{jk}(t_{12}) = \rho_{AB}^{jk}(t_2) - \rho_{AB}^{jk}(t_1) \qquad (7)$$

The significance of triple difference equation in the solution is that, by removing the integer ambiguities, the solution becomes immune to cycle slips. Cycle slips are created when the receiver loses lock during observation (Traugott et al, 2008). The three main sources of cycle slips are: Obstructions, low Signal to Noise Ratio (SNR), and Incorrect signal processing (Langley, 1999). The processing software will generate orbit files, compute the best fit point positions from the code pseudo ranges, compute an estimate of the vector components using the triple difference equation (5), compute baseline components (ΔX, ΔY, ΔZ) using the double difference equation (3), and compute statistical information for the baseline components.

3.0 Numerical Investigations

In the numerical investigations, the variations in the position vectors between the sessions were closely examined. In order to achieve this, the final adjusted coordinates of the observed stations were obtained from the processed data and the results from the two sessions were first compared with each other and also with their mean.

3.1 Inter-Sessional Difference

The two positions fixed (X_1, Y_1, Z_1 and X_2, Y_2, Z_2) from the double vectors observation at each station were compared, the shift (dX, dY, dZ) computed in each cases and analyzed. In order to minimize the effect of any possible error, the mean of each pair of determinations at all the stations occupied were obtained thus, the optimum co-ordinate of each rover station were derived; which were used to plot the traverse of the survey. However, comparing the mean (X_m, Y_m, Z_m) with each of the position obtained from adjusted observations (i.e X_1, Y_1, Z_1 for the first session and vice-versa), the residual from the mean was derived; which were used for analyzing the characteristics/ pattern of the errors.

4.0 Results and Analysis

4.1 Results

Tables 1-5 and fig.3-5 show the results and the graphical representations from various considerations. Table 1 shows the adjusted co-ordinates of all the rover stations, this was used to further generate table 2 and table 3, while the former shows the position vector with respect to the first determination at each station; the later presented the computation of the mean of determinations at each station.

Table 4 shows the variation of the adjusted observations from the mean and table 5a and b showed the statistics of the mean location and the residuals from the mean. While fig.3 is the graphical representation of table 3, fig. 4 and fig.5 are the graphical representation of tables 2 and 4 respectively.

Table 1. Adjusted co-ordinate of rover stations.

S/No	Pt. id	X_1 (m)	X_2 (m)	Y_1 (m)	Y_2 (m)	Z_1 (m)	Z_2 (m)	Remark
1	H566	565576.756		760978.540		103.653		base
2	H590	569759.840	569759.840	759104.241	759104.230	44.159	44.155	rover
3	A002	566105.813	566105.812	760702.152	760702.154	92.403	92.402	rover
4	A006	566984.853	566984.920	760234.782	760234.784	73.423	73.421	rover
5	A007	567204.138	567204.147	760116.888	760116.889	94.239	94.194	rover
6	A009	567612.499	567612.654	760050.061	760050. 203	89.885	89.668	rover
7	A010	567841.483	567841.912	760056.057	760055.793	79.883	80.358	rover
8	A011	568151.125	568151.076	760062.216	760062.239	48.164	48.088	rover
9	A012	568479.687	568479.493	760069.672	760069.611	63.797	64.24	rover
10	A013	568826.223	568826.185	759966.071	759966.064	70.809	70.728	rover
11	A018	569618.972	569618.976	759311.112	759311.118	61.679	61.681	rover
12	A005	566765.734		760352.840		63.928		rover
13	A008	567340.973		760044.459		96.240		rover

Table 2. Session difference per station

Pt, id	X1-X2 (dX)	Y1-Y2 (dY)	Z1-Z2 (dZ)
H590	0	0.011	0.004
A002	0.001	-0.002	0.001
A006	-0.067	-0.002	0.002
A007	-0.009	-0.001	0.045
A009	-0.155	-0.142	0.217
A010	-0.429	0.264	-0.475
A011	0.049	-0.023	0.076
A012	0.194	0.061	-0.443
A013	0.038	0.007	0.081
A018	-0.004	-0.006	-0.002

Table 3: Computation of the mean for the two sessions per station

Pt, id	X_1 (metres)	X_2 (metres)	X_m	Y_1 (metres)	Y_2 (metres)	Y_m	Z_1 (metres)	Z_2 (metres)	Z_m
H590	569759.840	569759.840	569759.84	759104.241	759104.230	759104.236	44.159	44.155	44.157
A002	566105.813	566105.812	566105.813	760702.152	760702.154	760702.153	92.403	92.402	92.403
A006	566984.853	566984.920	566984.887	760234.782	760234.784	760234.783	73.423	73.421	73.422
A007	567204.138	567204.147	567204.143	760116.888	760116.889	760116.889	94.239	94.194	94.217
A009	567612.499	567612.654	567612.577	760050.061	760050.203	760050.061	89.885	89.668	89.777
A010	567841.483	567841.912	567841.698	760056.057	760055.793	760055.925	79.883	80.358	80.121
A011	568151.125	568151.076	568151.101	760062.216	760062.239	760062.228	48.164	48.088	48.126
A012	568479.687	568479.493	568479.59	760069.672	760069.611	760069.642	63.797	64.24	64.019
A013	568826.223	568826.185	568826.204	759966.071	759966.064	759966.068	70.809	70.728	70.769
A018	569618.972	569618.976	569618.974	759311.112	759311.118	759311.115	61.679	61.681	61.68

Where, X_m is the mean of X_1 and X_2, Y_m is the mean of Y_1 and Y_2, Z_m is the mean of Z_1 and Z_2, while $X_{1,2}$; $Y_{1,2}$ and $Z_{1,2}$ are the easting and northing coordinates as well as height of the observed points respectively.

Table 4: Residuals from mean per station

Pt, id	X_m-X_1 (dX_1)	X_m-X_2 (dX_2)	Y_m-Y_1 (dY_1)	Y_m-Y_2 (dY_2)	Z_m-Z_1 (dZ_1)	Z_m-Z_2 (dZ_2)
H590	0	0	-0.005	0.006	-0.002	0.002
A002	0	0.001	0.001	-0.001	-0.0005	0.0005
A006	0.034	-0.033	0.001	-0.001	-0.001	0.001
A007	0.005	-0.004	0.001	0	-0.0225	0.0225
A009	0.078	-0.077	0.071	-0.071	-0.1085	0.1085
A010	0.215	-0.214	-0.132	0.132	0.2375	-0.2375
A011	-0.024	0.025	0.012	-0.011	-0.038	0.038
A012	-0.097	0.097	-0.03	0.031	0.2215	-0.2215
A013	-0.019	0.019	-0.003	0.004	-0.0405	0.0405
A018	0.002	-0.002	0.003	-0.003	0.001	-0.001

Table 5a: The Statistics of the mean Location

	Number	Minimum	Maximum	Mean	mean sq error
Xm	10	566105.8125	569759.8	568058.5	1156.926
Ym	10	759104.2355	760702.2	759967.3	452.597
Zm	10	44.157	94.2165	71.8688	17.672

Table 5b: The Statistics of the residuals from the mean

	Number	Minimum	Maximum	Mean	mean sq error
Xm-X1	10	-0.097	0.215	0.0194	0.081702
Xm-X2	10	-0.214	0.097	-0.0188	0.081442
Ym-Y1	10	-0.132	0.071	-0.0081	0.050441
Ym-Y2	10	-0.071	0.132	0.0086	0.05041
Zm-Z1	10	-0.1085	0.2375	0.0247	0.112909
Zm-Z2	10	-0.2375	0.1085	-0.0247	0.112909

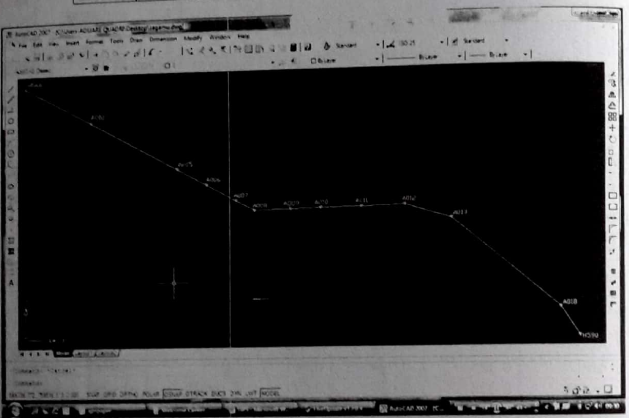

Figure 3: The Traverse Plan

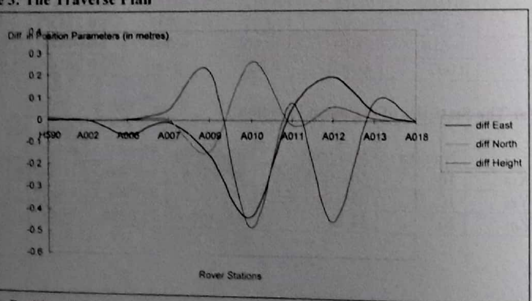

Fig. 4: Positional difference

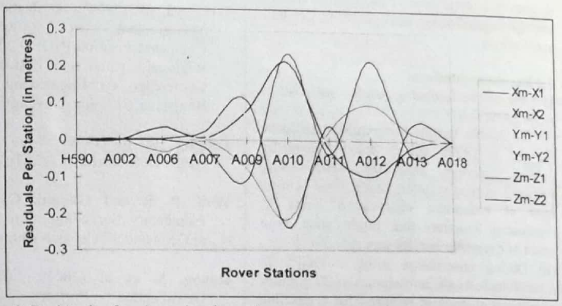

Fig. 5: Residuals of each session from the mean

4.2 Analysis

The processed results from the GNSS Solution software showed a maximum error of 6.5cm, 6.7cm and 6.2cm in the vectors dX, dY and dZ respectively only at station A06 at 95% confidence interval. However, the residuals of the adjusted vectors indicated a high level of correlation between the vector components of the first and the second sessions at each station. Nevertheless, there is a relatively high discrepancy noticed at stations: A09 with residuals values of -25.7cm, 13.6cm and 11.8cm for the fist session and zero for the second session in X, Y, Z respectively; A010 has residuals for the two sessions respectively as: -30cm, -30.3cm, 14.5cm and 11.5cm, 14.1cm and -7cm, similarly, for A011, we have: 18cm, 18.8cm and -7.2cm as well as 15.2cm, 13.5cm and -8.5cm respectively in X, Y, Z for the two sessions. These errors are still large in precise Surveying applications, therefore, in order to further study the reliability of the determinations, the difference between the co-ordinates as presented in table2 was plotted (fig.4), the result expectedly presented a relatively large discrepancy at A09, A010 and A012. From the statistics of the mean determinations per station as indicated in table5a and b above, the mean square errors in X_m, Y_m and Z_m are 1156.926m, 452.597m and 17.672m respectively; while, the mean square errors for the residuals of each session from the mean were 8.170cm, 8.144cm, 5.044cm, 5.041cm, 11.291cm and 11.291cm respectively for X_1, X_2, Y_1, Y_2, Z_1 and Z_2 which is an indication of improvement in the data quality. From the result in table 4 and the graphical representation in fig. 3, it was observed that the resulting residuals from the mean have equal magnitude and opposite sign; therefore, they are normally distributed. Hence it could be concluded that the errors cancelled out which implied that the mean of the double vectors gives the optimum values for the observed points.

5.0 Conclusion and Recommendations

5.1 Conclusion

Double vectors analysis of DGPS data in static relative mode has been discussed, difference between repeated measurements of the same base line components were employed in evaluating the consistency of the observed data, and in weeding out blunders. These repeated measurements were taken in different observed sessions at each station and the results compared as shown in tables 1 to 4 above. From the foregoing results and the concluding analysis, the mean of repeated measurements of the same base using Promak3 Differential Global Positioning

System in a static relative mode is a veritable tool for higher order surveying and geodetic applications.

5.2 Recommendations:

In view of the foregoing results, we wish to recommend that:

(i) The double vectors observation should be adopted in DGPS survey for higher order geodetic surveys, especially when using Promak3 in relative static mode. This being a kind of redundant observation helps in eliminating blunders that might arise as a result of cycle slip in GPS survey.

(ii) During observation using a DGPS in relative static mode, a minimum of 20 minutes of occupation time is required for a baseline length of about 100m. This allows for proper resolution of cycle slip errors arising from factors such as low Signal to Noise Ratio (SNR), and incorrect signal processing.

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