APPLYING NEW APPOACHES FOR IMPROVING THE ON-THE-FLY (OTF) AMBIGUITY RESOLUTION PROCESS...

Article · September 2001

2 authors:

Ahmed Elhattab
Port Said University

Mostafa Rabah
Benha University

APPLYING NEW APPOACHES FOR IMPROVING THE ON-THE-FLY (OTF) AMBIGUITY RESOLUTION PROCESS OVER LONG BASELINES

By

Ahmed El-Hattab[*] ,Mostafa Rabah[**]

*The Faculty of Engineering, Suez Canal University, Port-Said, Egypt

**The National Research Institute of Astronomy and Geophysics, Egypt, Cairo, Helwan

1. Abstract

Nowadays, precise instantaneous real-time application, such as precise navigation, is representing one of the over-increased demands. To provide precise positioning with a few centimeters accuracy for long baselines, the phase ambiguity must be correctly resolved while the receivers are in motion. The research in the field of kinematic real-time ambiguity resolution for long baselines is still one of the inevitable barrier to achieve the ultimate precision of GPS. This research introduces an algorithm for solving the double-difference (DD) Wide-Lane ambiguity of long baselines.

The developed algorithm utilizes the wide-laning technique for getting an accurate estimation of the Wide-Lane (WL) ambiguity float solution. The accuracy of this float solution is investigated. A new criterion is used for fixing the correct group of WL ambiguities. A verification of the applied algorithms is done for a kinematic experiment of baseline length ranging from 145 km to 155 km.

Key words

GPS, Ambiguity resolution, long baselines, RTK

2. Introduction

As it is commonly known that the modeling of GPS measurements is always the most important constituent for retrieving the desired information from GPS observables. The GPS carrier phase observations are associated with measurement noise at the millimeter level. However, the phase ambiguity must be estimated and its integer value must be identified. Resolving the integer ambiguity effectively turns carrier phase data into precise ranges with millimeter-level noise so the highest accuracy is always achieved when integer solution is obtained.

The GPS observations are affected by several kinds of errors and biases when forming the double-difference, while the satellite and the receiver clock errors are eliminated. The remained residuals are the uncorrelated part of the orbital errors, the ionosphere and the troposphere delays as well as the multi-path and the receiver noise. With increasing the baseline length, these uncorrelated errors are increased. The effects of these residuals are reflected on the resolution process of the phase ambiguities.

The developed algorithm estimates the float WL ambiguities using the wide-laning technique to improve the accuracy of the float solution. The comparisons between the float WL ambiguities estimated using the direct method and the wide-laning technique are investigated in this research. To improve the ambiguity resolution process that used in *[El-Hattab, 1998]* to be able to resolve the ambiguities for long baselines over 100 km a new criterion is applied. A verification of the developed algorithm is performed for a kinematic experiment of instantaneous baseline length ranging from 145 km to 155 km.

3. The Effect of DD-GPS Biases on the Ambiguity of the linear combinations

Carrier phase observables in GPS include sum of range, unknown integer ambiguity and some ranging errors. Since the carrier phase observables contain much smaller measurement errors than code observables, much effort have been given to develop techniques to exploit the carrier phase observables by fixing the unknown integer ambiguities. To facilitate the ambiguity resolution fixing process, by eliminating and reducing some biases, the GPS double-difference techniques of different GPS observation linear combinations are utilized. The primary double-difference phase and pseudorange observables that are used in the different linear combination can be mathematically modeled as:

$$\lambda_i DD(\varphi_i) = DD(R) + \lambda_i DD(N_i) - DD(I_i) + DD(T) + MP + G + \varepsilon_\varphi \qquad (1)$$

$$DD(\rho) = DD(R) + DD(I) + DD(T) + MP + G + \varepsilon_\rho \qquad (2)$$

Where:

φ_i	carrier phase observations, subscript i denotes to L1 or L2 (cycles)
λ_i	wavelength (m)
ρ	code observations (m)
R	geometric range between the station and the receiver (m)
N	carrier phase ambiguity
I	ionosphere effect (m)
T	troposphere effect (m)
MP	multi-path effect
G	the combined effect of orbit bias and the residual of troposphere modeling , as well as the position error of both the reference and the rover (it is considered as a single error, namely the geometric error)
ε_φ	carrier phase noise
ε_R	pseudorange noise

To form the different linear combinations, by assuming that the phase and the frequency of L1 and L2 is φ_1, f_1 and φ_2, f_2, the following general form of linear combinations is used and can be defined as:

$$\phi_{a,b} = a\phi_1 + b\phi_2 \qquad (3)$$

$$f_{a,b} = a f_1 + b f_2 \qquad (4)$$

The magnitude of the ionosphere delay on the linear combination can be written as a function of the magnitude of ionosphere effect on L1 signal (I_1) *[Abidin, 1993]* as:

$$ISF = \frac{f_1}{f_2} \frac{af_2 + b_{f1}}{af_1 + bf_2} \tag{5}$$

Where: *a*, *b* are arbitrary numbers representing the coefficients of the linear combination. *ISF* is called ionosphere scale factor of the nominated linear combination with respect to the ionosphere of L1. The wavelength of the formed linear combination observation can be computed as:

$$\lambda_{a,b} = c / f_{a,b} \tag{6}$$

To demonstrate for what range can these biases affect the ambiguity resolution of any different linear combination, one can get from equation (1):

$$DD(N_{a,b}) = DD(\varphi_{a,b}) - (DD(R) + DD(T)) / \lambda_{a,b} + G / \lambda_{a,b} + ISF.DD(I_1) / \lambda_{a,b} + \varepsilon_{a,b} \tag{7}$$

Equation (7) can be reformulated as:

$$DD(N_{a,b}) = DD(\varphi_{a,b}) - (DD(R) + DD(T)) / \lambda_{a,b} + AGF.(G) + AIF.DD(I_1) + \varepsilon_{a,b} \tag{8}$$

Where:

AGF The effect of geometry bias on the ambiguity value, it is called the ambiguity geometry factor.

AIF The effect of ionosphere bias on the ambiguity value, it is called the ambiguity ionosphere factor.

The *ISF*, *AIF* and *AGF* have been calculated for the most common linear combinations, their values have been tabulated in table (1).

a	b	Wave-length (m)	ISF	AIF	AGF
-7	9	14.5626	350.3500	23.91041	0.06825
-3	5	0.21236	3.81280	17.95470	4.70906
-3	4	1.62807	18.2520	11.21074	0.61422
-2	3	0.56356	5.47885	9.72182	1.77443
-1	2	0.34076	2.80543	8.23289	2.93463
0	1	0.24421	1.64694	6.74396	4.09483
1	0	0.19029	1.00000	5.25504	5.25504
2	-1	0.15588	0.58706	3.76611	6.41524
4	-3	0.11447	0.09023	0.78826	8.73564
5	-4	0.10100	-0.07000	0.69300	9.9
1	-1	0.85852	-1.28333	-1.49482	1.16480

Table (1): The effect of the ionosphere and geometry biases
On the ambiguity value

In case of geometry free linear combination, the *AIF* equals 203.9, while for ionosphere free linear combination, the *AGF* equals 160.38. Based on the values that have been outlined in table (1), one can easily see the effect of the *AIF* and *AGF* on the different linear combination. As it is indicated in table (1), the Wide-Lane (WL) linear combination is the only one that has reasonable values of *AIF* and *AGF.* On the other hand, the other linear combinations have suffered from both the ionosphere and/or geometry effect. Generally, in case of long baselines, both the ionosphere and orbit biases increase with increasing the baseline length. In the OTF ambiguity-fixing algorithm, one needs a good approximation for the known points. As the position approximated value is near to the real value, the ambiguity fixing process becomes more successful and vices versa. Two commonly methods have been applied to get an approximate solution for the unknown point. The first method utilises the code observations, as it is commonly used for short baseline applications. The second uses the linear combination of phase observation, namely the wide-lane observations, as in the case of long baselines.

4. Real-Time Wide-Lane Ambiguity Resolution for Long Baselines

Resolving the wide-lane ambiguity is considered the main key for the real-time L1 and L2 ambiguity resolution for long baselines, especially for kinematic applications. By solving the wide-lane ambiguities, one can determine relatively precise position for the rover receiver within a few centimeter to decimeter accuracy, surpassing the accuracy of the position obtained by a code pseudoranges solution. Hence, this will contribute in reducing the search volume of the other ambiguity groups.

4.1. Determination of the Float Double Difference Wide-lane Ambiguity in Real-time

The wide-lane ambiguity resolution for long baselines On-The-Fly proceeds in three stages as shown in figure 3. The first stage is estimating the initial primary (float) ambiguities using the extra-widelaning method. That set of ambiguities is considered as the center of the ambiguity searching space. Each set of ambiguities inside the searching domain will be a candidate for the solution. The second stage is testing each candidate set of ambiguities with some rejection and validation criteria. The remained sets of ambiguities, which are validated by all of the tests, will be stored with the next epoch to be tested with the same criteria. This process is repeated till the remained set of ambiguities is only one set. The remained set of ambiguities is fixed in the third step of the ambiguity resolution process when it verifies some warranty criteria.

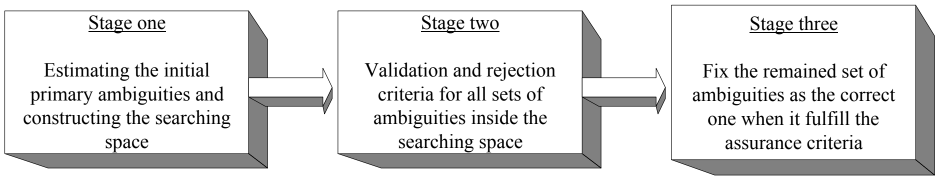

Figure (3): Block diagram for the long baseline ambiguity resolution.

The extra wide-laning technique uses the code pseudoranges and carrier phases in a way such that they remove the effect of geometric and ionosphere biases. The observation equation for the wide lane linear combination can be written as:

$$\lambda_{WL} DD(\varphi_{WL}) = DD(R) + \lambda_{WL} DD(N_{WL}) - DD(I_{WL}) + DD(T) + MP + G + \varepsilon_{WL} \quad (9)$$

The observation equations for the NL linear combination for the double-difference code pseudoranges can be written as:

$$DD(\rho_{NL}) = DD(R) + DD(I_{NL}) + DD(T) + G + \varepsilon_{NL} \quad (10)$$

where:

$$DD(\rho_{NL}) = \frac{f_1.DD(\rho_1) + f_2.DD(\rho_2)}{f_1 + f_2} \quad (11)$$

The noise and multi-path effect on the pseudorange, can be reduced by smoothing by the carrier phase observations, as described by *[Hatch, 1982]*. The wide-lane ambiguities can be estimated by using the combination of wide-lane carrier phase, and smoothed narrow-lane pseudorange. The float double difference wide-lane ambiguities can be computed as:

$$floatDD(N_{WL}) = \frac{DD(\varphi_{WL}) - DD(\rho_{NL})}{\lambda_{WL}} \quad (12)$$

The advantages of this algorithm are; it can be used in static or kinematic applications, of course in real-time too, as well as it is baseline length independent; and the computed wide-lane ambiguity has no effect of the geometric errors and ionosphere effects. On the other hand, the disadvantage of the computed wide-lane ambiguity is that; it is mainly affected by the code specific errors of the codes, namely the code observation noise; and the multi-path effect. To avoid the code inherent errors in computing the wide-lane ambiguities, the available alternative is the direct method to compute the WL float solution as following:

$$floatDD(N_{wL}) = DD(\varphi_{WL}) - \frac{1}{\lambda_{WL}}(DD(R) + DD(I_{WL}) + DD(T)) \quad (13)$$

Where the geometrical range DD(R) is computed from the solution that is based on DD-code observables.

4.2 Evaluation the Wide-Lane Determination Methods

To evaluate the quality of the computed float WL ambiguity computed by the extra-wide-laning technique and the direct method, figure (1) depicts the epoch by epoch wide-lane ambiguity solution of satellite PRN (28) of a baseline which connects the two stations, (Carrhil and Cicese) with length 565.201 km. The differences between the ambiguity fixed value and the float values computed by the extra-widelaning methods and the direct method for the baseline that connects Carrhil with Cat1 with length 324.451 km is shown in figure (2). As it is indicated in both figures, the differences between the fixed value of the wide-lane ambiguity and the float solution of the first one in the range of less than one cycle. On the other hand, these differences exceed more than 1 cycle for the second one.

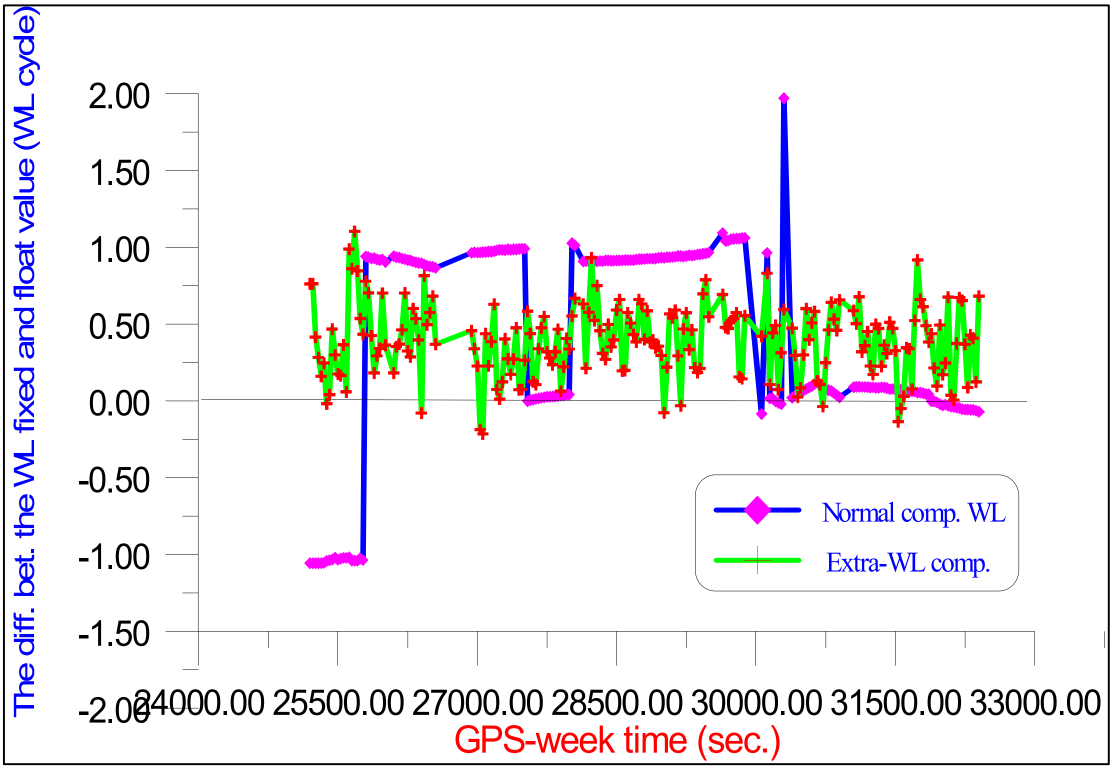

Figure (1): the epoch by epoch differences between the fixed wide-lane ambiguity and float values of satellite PRN (28) of abaseline which connects the two stations, Carrhil and Cicese (USA) with length 565.201 km.

Finally, it is concluded that the, in the worst case, the upper limit for the search interval for the extra-widelaning method is in the range of ±2 wide-lane cycles. In addition, it is completely independent of the baseline length. On the other hand this upper limits for the direct method is dependent on the baseline length and can reach several cycles.

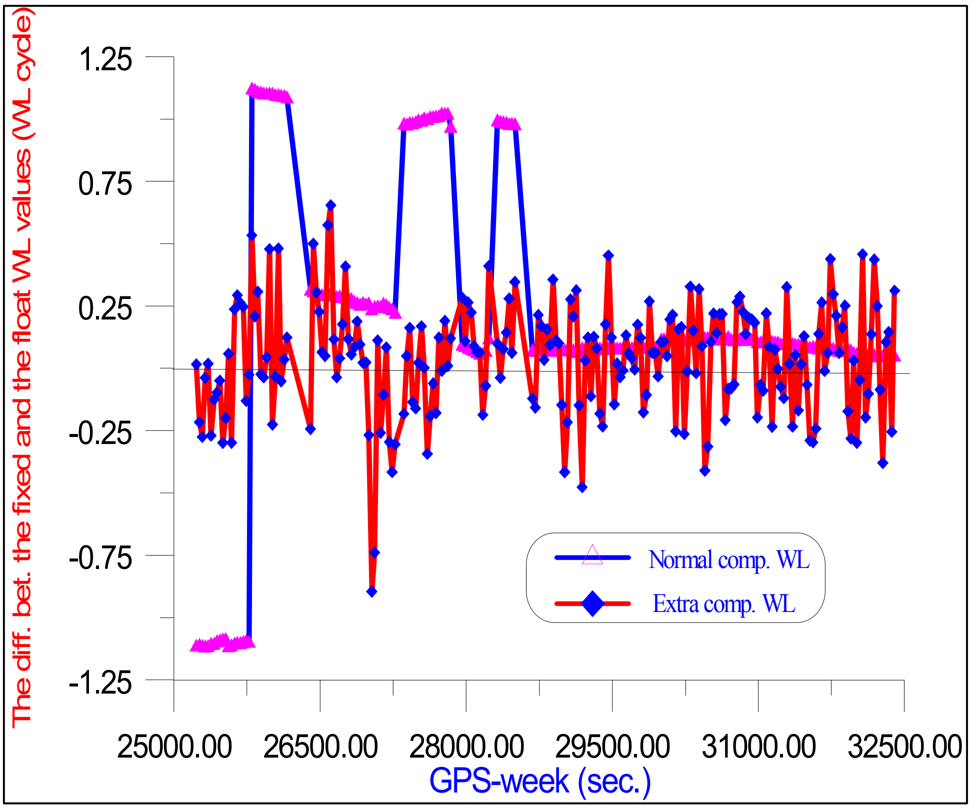

Figure (2): the epoch by epoch differences between the fixed wide-lane ambiguity and float values of satellite PRN (28) of baseline which connects the two stations, Carrhil and Cat1 (USA) with length 324.451 km.

5. The Real-Time Wide-Lane Ambiguity Fixing Criteria for Long Baselines

The wide-lane ambiguity resolution for long baselines On-The-Fly proceeds in three stages as shown in figure 3. The first stage is estimating the initial primary ambiguities using the extra-widelaning method, that set of ambiguities is considered as the center of the ambiguity searching space, each set of ambiguities inside the searching domain will be a candidate for the solution. The second stage is testing each candidate set of ambiguities with some rejection and validation criteria. The remained sets of ambiguities, which are validated by all of the tests, will be stored with the next epoch to be tested with the same criteria. This process is repeated till the remained set of ambiguities is only one set. The remained set of ambiguities is fixed in the third step of the ambiguity resolution process when it verifies some warranty criteria.

The applied technique employs the facts that the double-difference ambiguities corresponding to four satellites mathematically determine the other ambiguities related to the remained satellites. So, it is only essential to search for three double-difference ambiguities regardless of the total number of ambiguities [*Hatch, 1990*]. Three double-difference ambiguities related to the reference station, which are call the primary ambiguities will be searched for. The other ambiguities related to main are mathematically dependent on the primary ambiguities.

5.1 The Searching Procedures for the Correct Set of Ambiguities

The search for the correct set of ambiguities is performed in a three dimension searching space constructed by the set of the primary ambiguities that are determined by the extra-widelaning technique. A cube centered at the initial primary ambiguities is constructed to be the ambiguity searching space.

After constructing the searching space, each set of ambiguities inside that searching domain would be a candidate for the solution. Some validation and rejection criteria are applied to distinguish the correct set of ambiguities from the other primary sets of ambiguities inside the searching space. Figure (4) shows in sequence the validation and rejection criteria, which are used to identify the correct ambiguity set.

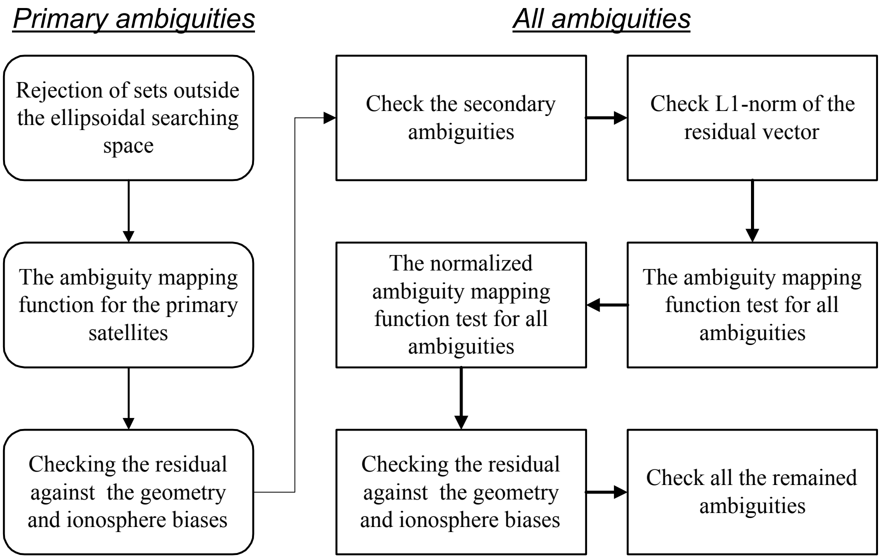

Figure (4): The rejection and validation criteria.

Concerning the checking the position residual against the ionosphere and geometry biases, as it is indicated in equation (8) and table (1), the position of the baseline unknown point is affected by the geometry and ionosphere biases that are still incorporated in the observation equation after fixing the wide-lane ambiguity. The position of the correct fixed ambiguity group must reflect these effects, otherwise it is not the correct group. Contradicting with the common methods, the new approach do not consider the ambiguity group that gives the minimum value of the quadratic form of the residual as the correct group, but it consider the group that verifies the following criteria is possible correct group.

$$\sigma_{ion}^2 - \sigma_{geo}^2 < \left(v^t p v\right)_i < \sigma_{ion}^2 + \sigma_{geo}^2 \qquad (14)$$

Where:

$\left(v^{t}pv\right)_{i}$	Quadratic form of the residuals related to the trial set of ambiguities number i.
σ^{2}_{ion}	The variance of DD-ionosphere bias;
σ^{2}_{geo}	The variance of DD-geometry bias.

The variances of the ionosphere and geometry biases are computed according to *[Yang, 1995]* and *[Rabah, 1999]*. *[Yang, 1995]* has suggested an exponential model for computing the variance of double difference ionosphere observations as a function of baseline length *(d)*. The Yang ionosphere exponential model is formed for double-difference ionosphere delays as:

$$\sigma^{2}_{DD} = (\sigma^{2}_{\infty})(1 - e^{-2|\tau|/T})(1 - e^{-2d/D}) \qquad (15)$$

Where:

σ^{2}_{DD}	The variance of double difference ionosphere delay observations.
σ^{2}_{∞}	The variance of double difference ionosphere delay at a distance D and equal to $2\,m^{2}$.
τ & T	The epoch interval and correlation time consecutively.
D	The correlation distance parameter, D is taken as *1500 km* (the upper limit of all practical kinematic GPS).
d	The instantaneous baseline length *(km)*.

The variance of the DD-geomety error is computed as a function of baseline length l and the height difference Δh between the baseline two ends *[Rabah, 1999]* , as:

$$\sigma_{geo}^2 = \sigma_{\circ}^2\,(1 - e^{-(l/L + \Delta h/H)})(1 - e^{-2\upsilon|\tau|}) \qquad (16)$$

Where:

L	The maximum correlation distance, 1000.0 km
H	The maximum correlation height, 10km.
$\sigma_{\circ}^2$	The variance of the DD-geometry error when the length of the baseline reaches maximum distance and the height difference reaches the maximum height, 12 cm$^{2.}$

6. Verification the Real-Time Wide-Lane OTF Ambiguity Resolution Algorithm

In order to verify the contribution of the developed algorithm, a kinematic experiment parallel to the Suez-Canal between Port-Said and Esmaillia was made with length of 71 km. The reference station was at Aldalgmoun, about 140-150 km with respect to the trajectory of the kinematic experiment as shown in figure (5). To verify the correctness of the ambiguities while in motion, several stops of the car were made for a few minutes during the kinematic experiment. The positions of the rover antenna during those stops were estimated relative to the nearest reference station, either Port-Said or Esmaillia, by Bernese software version 4.0 *[Rotacher el. al, 1996]*. In addition, by using the known coordinates, an estimate for the wide-lane ambiguity group is computed.

To validate the developed algorithm, the OTF program that has been developed by *[El-Hattab, 1998],* namely Extended On The Fly (EXOTF97), is tested in solving the current kinematic experiment relative to Aldalgmoun as a reference station. The resulting wide-lane ambiguity groups are compared with the correct related group of each stop. It was found the developed algorithm has succeeded in fixing the ambiguities after only several epochs. The ambiguity values are stated in table (2).

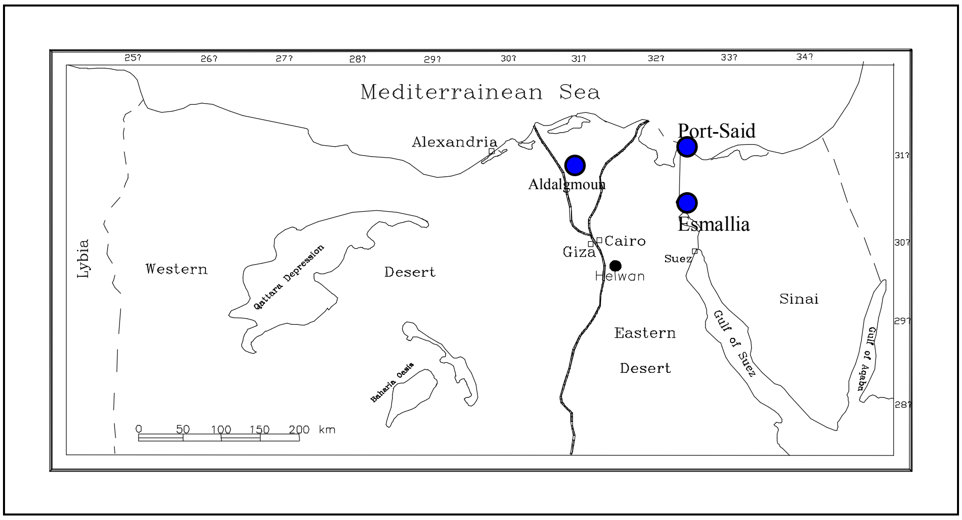

Figure (5): The geometry configuration of the experiment

PRN	WL ambiguity of the 1st stop		WL ambiguity of the 2nd stop		WL ambiguity of the 3rd stop	
	EXOTF sol.	Developed Algorithm	EXOTF sol.	Developed Algorithm.	EXOTF sol.	Developed Algorithm
29	2040936.0	2040936.0	2040956.0	2040957.0	----	----
14	1880360.0	1880359.0	1880365.0	1880367.0	-160588.0	-160588.0
25	3118880.0	3118881.0	3118858.0	3118861.0	1077893.0	1077893.0
31	-123672.0	-123671.0	---	---	----	----
18	---	---	3540042.0	3540041.0	1499078.0	1499078.0
15	---	---	---	---	-2040957.0	-2040959.0

Table (2): Evaluation of the EXOTF97 program in resolving the ambiguity of the kinematic experiment

7. Conclusions

It is clear from the given algorithm and the related test that neglecting the effect of the ionosphere and geometric biases in the wide-lane ambiguity searching process of long baseline will lead to pseudo fixing process. The common statistical criteria that utilize the minimum residual is not correct to be applied over long baselines.

8. References

1. ABIDIN H. (1993): *Computational and Geometrical Aspects of On-the-Fly Ambiguity Resolution.* Ph.D. dissertation, Surveying Engineering Technical Report No. 164, University of New Brunswick, Canada.
2. BLEWITT G. (1989): *Carrier phase ambiguity resolution for the global positioning system applied to geodetic baselines up to 2000 km*. Journal of Geophysical Research, Vol. 94, No. B8, pp. 10187-10203.
3. DEDES G. and MALLETT A. (1995): *Effects of the Ionosphere and Cycle slips in Long Baseline Dynamic Positioning*. Proceedings of the ION GPS 95, Palm Springs, California, USA.
4. EL-HATTAB A. (1998): *Developing automated navigation control system using the Global Positionimg System (GPS) across Suez-Canal.* Ph. D. Thesis, Suez-Canal University, Egypt.
5. EULER H.-J. and GOAD C.C. (1991): *On optima filtering of GPS dual frequency observations without using orbit information.* Bulletin of Geodisque 65, pp. 130-134.
6. GOAD C.C. (1992): *Robust techniques for determining GPS phase ambiguities.* Proceeding 6 th International Geodetic Symposium on Satellite Positioning, Columbus, Ohio, 17-20 March, pp. 245-254.
7. HATCH R. (1990): *Instantaneous Ambiguity Resolution*. Proceeding of IAG Symposium No. 107, Banff, Alberta, Canada.
8. HATCH R. (1986): *Dynamic differential GPS at the centimeter level.* Proceeding 4th International Geodetic Symposium on Satellite Positioning, New Mexico, 13-17 March, pp. 452-461.
9. HATCH R. (1982): *The synergism of GPS code and carrier measurements.* Proceeding of the third International Symposium on Satellite Doppler Poitioning, New Mexico state University, February 8-12, Vol. 2, pp. 1213-1231.

10. LEINEN S. (1997): *Hochpräzise Positionierung über große Entfernungen und in Echtzeit mit dem Global Positioning System.* DGK, Heft 472, Deutchland.

11. MADER G. (1992): *Kinematic GPS Phase Initialization using the Ambiguity Function.* Proceedings of 6th International Geodetic Symposium on Satellite Positioning, Columbus, Ohio (USA).

12. RABAH M. (1999): *Developing a Real-Time Model to Reduce the Geometric Delay Residuals in Double-Difference GPS Observations Over Long Baselines.* Arbeit fuer Vermessung Nachrichten, May 1999, Weichmann Verlag.

13. ROTHACHER M. and MERVAT L. (Eds.) (1996): *Bernese GPS Software Version 4.0.* Astronomical Institute, University of Berne, Berne, Switzerland.

14. SONNTAG J.G., MARTIN C.F. and KRABILL W.B. (1995): *Ambiguity Resolution Over Long Baselines for Airborne Differential GPS Positioning.* Proceedings of the ION GPS-95, Palm Springs, California (USA).

15. WÜBBENA G. (1989): *The GPS adjustment software package"JEONAP" concepts and models.* Proceeding of the 5th International Geodetic Symposium on Satellite Positioning. Las Cruces, New Mexico, 13-17 March, 452-461.

16. YANG M. (1995): *New GPS measurements modelling techniques of orbit determination and precise kinematic positioning*. Report No 341, Dept. of Geodetic Sceince and Surveying, Ohio State University, Colombus, Ohio, USA.