Assessment of single frequency receivers in relative point positioning

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Global Positioning System (GPS) is widely used in civilian purposes especially in surveying and geodesy. Geodesists and surveyors achieved a high precision in surveying using GPS particularly Differential (Relative) type. In last decade, GPS receivers have been developed and many capabilities have been added. SO, GPS receivers are used in both static and kinematic positioning. Geodesists and surveyors have high confidence in using dual frequency GPS receivers; because the previous studies proved that using this type of receivers achieved a high precision in surveying. But the confidence is less when using single frequency receivers, although the price of single frequency receivers is cheaper. So, this study is carried out to test the performance of using single frequency receivers in surveying field. Nine new stations have been established in Alexandria city with differential baselines to a reference point. The reference point has been previously fixed on the roof of the administration building in the faculty of engineering. Observations have been taken using dual frequency receivers and also using single frequency receivers. The results obtained from dual frequency receivers were considered a base for comparison. All results have been set out through many plots showing the variation of various parameterts. Results gave a reasonable precision when using single frequency receivers in surveying.

يستخدم نظام التثبيت العالمي GPS بصورة كبيره في المجالات المدنية المتعدده و منها مجال المساحة و الجيوديسيا. اثبت نظام GPS مكانة عاليه عند مستخدميه في مجال المساحه، و خاصة عند تثيت النقط بالنظام النسبي (Differential) كما أن المرونة في استخدام مستقبلات GPS و الامكانات التي اضيفت اليها في الاونه الاخيره و ذلك من وضعي الثبات و الحركه أعطت توسعاً كبيراً في استخداماته في المساحه. ان ثقة علماء الجيو ديسيا و المساحين و المستخدمين في مستقبلات GPS ثنائي التردد عاليه جداً لما اثبتته الدراسات السابقه في تحقيق دقه عالية و مناسبه لاستخدامات المساحه و الجيوديسيا. و الثقه تقل في استخدام مستقبلات GPS احادية التردد و لكن ننظر الي فرق السعر بين المستقبلين حيث ان سعر مستقبل GPS ثنائي التردد يقرب من ضعف سعر مستقبل GPS احادي التردد. و لذلك قمنا في هذه الدراسه بتثبيت تسع نقاط في مدينة الاسكندريه و استخدمنا نقطة ثابتة سابقة التصحيح و معلومة الاحداثيات عالمياً بنظام GPS حيث سبق تثبيتها بدقة فى بحث سابق و هي فوق سطح مبني الاداره بكلية الهندسة. قمنا بعمليات الرصد بجهاز GPS ثنائي التردد موديل (Ashtech Z-Surveyor). و أعدنا رصد النقاط كلها باستخدام جهاز GPS احادي التردد موديل (Stratus). و اعتبرنا النتائج من أرصاد المستقبل ثنائي التردد أساس للمقارنة بها. وتم توقيع كل النتائج خلال منحنيات لدراسة مدي الدقه التي حققها استخدام المستقبل احادي التردد في تثبيت النقط و تأثير زيادة ونقصان تردد الاشارات علي الدقه و أيضاً تأثير المدة الزمنيه للرصد علي الدقه.

Keywords: GPS, Single frequency, Dual frequency, Geodetic accuracy

1. Introduction

Carrier phase-based Global Positioning System (GPS) positioning is now an indispensable tool for a wide range of precise applications in navigation, surveying and geodesy. To address such a variety of applications, many implementations of precise GPS techniques have been developed. Almost all techniques involve relative positioning in which one GPS receiver/ antenna's coordinates are determined with the aid of measurements also made at stationary base or reference receiver [1]. GPS relative positioning, also called differential positioning, employs two GPS receivers simultaneously tracking the satellites to determine their relative coordinates. Of the two receivers, one is selected as a reference; or base; which remains stationary at a site with precisely known coordinates. The other receiver; known as the rover or remote receiver; has its coordinates unknown. The rover receiver may or may not be stationary depending on the type of GPS operation. Carrier- phase and\ or pseudo range measurements can be used in relative positioning. Using carrier-phase measurements, an accuracy level of a sub centimetre to a few meters can be obtained. This is mainly because the measurements of two receivers simultaneously tracking a particular satellite contain more or less the same errors and biases. The shorter the distance between the two receivers, the more similar the errors. Therefore, if we take the difference between the measurements of the two receivers (hence the name "differential positioning"), the similar errors will be removed or reduced [2].

Observation equation for phase is shown below [3].

$$\Phi = \rho + c\,(dt - dT) + \lambda N - d\,\text{ion} + d\,\text{trop} + d\rho$$

Where:

Φ	is the observed carrier phase,
ρ	is the geometric range expressed as a function of the receiver and satellite coordinates,
c	is the speed of light,
dt	is the satellite clock bias,
dT	is the receiver clock bias,
λN	is the initial ambiguity,
d ion and d trop	are the atmospheric delay parameters, and
$d\rho$	is the orbital error.

In this work, technique of triple differencing was implemented. So, ionosphere error and troposphere error (d ion and d trop) were reduced. Also, satellite orbit error ($d\rho$), satellite clock error (dt), receiver clock error (dT) and ambiguity error (λN) were removed.

For short baselines using conventional techniques, single frequency receivers are sufficient. For conventional static GPS over longer baselines where high accuracies are sought, dual frequency receivers are desirable since they permit correction of most of the ionospheric errors [4].

2. Purpose of the investigation

GPS has become a widely used tool in all positioning activities, especially for the surveying field. Now, the surveyors are using dual frequency receiver observations in differential mode instead of traditional surveys to achieve the accuracy requirements of the geodetic networks. Recently, GPS modernization, revolution in receiver technology and processing software development has resulted in a great improvement in the achievable accuracy for GPS receivers. The best accuracy can be obtained by using dual frequency GPS receivers, but the price of a dual frequency receiver is very high compared to a single frequency receiver.

In this research, it was thought that using a single frequency receiver is accurate enough for most surveying work, provided that care is taken in applying all possible corrections and techniques to obtain the utmost accuracy. It is aimed in this investigation to evaluate on a practical basis the performance of Stratus instrument as a representative of single frequency receiver with a view to develop recommendations to obtain surveying accuracy. For comparison and calibration, a dual frequency receiver namely (Ashtech Z-Surveyor) was used as a standard for evaluation. The comparison is made investigating the variation of different parameters such as distance, interval, mask angle and duration.

3. Capturing of data

3.1. The reference point

A station (Alex1), located at the Faculty of Engineering, Alexandria University, was fixed using a dual frequency instrument in conjunction with nine IGS (International GPS Service) stations distributed around the middle east region. Raw data at station Alex.1 were collected by Trimble 4000SSE dual frequency receiver and simultaneous data from IGS stations were downloaded from the internet. The processing yielded accurate coordinates of Alex1 for various combinations of base station for dual frequency (L1 and L2) observations for observation time of 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 2 hour, 4 hour, 8 hour, 12 hour, and 34 hour. The final accurate coordinates for Alex.1 are shown in table 1 [5].

Table 1
Captured coordinates of ALEX1

Coordinate type	Coordinates	Standard deviation
Geographical	λ = 29° 55' 26.34023" E	0.007
	φ = 31° 12' 21.46656" N	0.008
	H= 62.185 m	0.024
Geocentric	X = 4732331.678 m	0.009
	Y = 2723847.897 m	0.01
	Z = 3285478.329 m	0.030

3.2. Instrumentation and equipment

A practical study was done to evaluate the accuracy of relative positioning using a single frequency receiver versus a dual frequency receiver. Two main sessions of collecting data were carried out. In the first session, data were collected using Ashtech dual frequency receiver; a lot of thanks to Surveying System Company for lending us this instrument. In the second session, data were collected using a Stratus single frequency receiver. Stratus is a complete single frequency GPS receiver system for precise surveying. The Stratus system components include the Stratus integrated receiver, data post processing software, and all the necessary accessories to yield quality results with minimal time and effort. The receiver is a compact, high integrated electronic device that incorporates a survey-grade GPS receiver antenna, and batteries. The receiver collects and records signals broadcast from satellites and stores this information in its internal memory. Stratus receiver specifications stated by the manufacturers are shown in table 2 [6].

3.3. Data observations

Three sets of stations have been established for observation. The first set, which has a baseline 1 km long approximately to the reference point, has the following sites: St2- Ahmed, St3- Delta, and St4- ELkornish. The second set, which has a baseline 7km long approximately to the reference point, has the following sites: St5- Abis, St-6 after Carefour, and St-7 Alwardian. The third set, which has a baseline 22km long approximately to the reference point, has the following sites: St8- K21, and St9- Kafr Eldwar. Fig. 1 illustrates a net sketch of the sites. One receiver was fixed at the reference point and the other receiver was used as a rover at all stations. A sample of the data which has been collected is shown in table 3.

4. Data analysis

The coordinates of all eight stations were obtained using the dual frequency receiver. Also, these coordinates were obtained using the single frequency receiver. Results of dual frequency receiver were considered as a

Table 2
Stratus receiver specifications

Stratus GPS receiver	
Static performance	5 mm + 1 ppm (horizontal)
	10 mm + 2 ppm (vertical)
Kinematic performance (stop-and-Go)	12 mm + 2.5 ppm (horizontal)
	15 mm + 2.5 ppm (vertical)
Dimensions (H x D)	125 mm x 155 mm (5 in x 6 in)
Weight w/o batteries	0.62 kg (1.38 lb)
Weight with batteries	0.80 kg (1.75 lb)
Memory	4 MB (internal)
Memory life	55 hours 10 s
	11 hours 2 s (8 satellites)
Battery type	2 x BDC46 rechargeable batteries
	30 hours (at 20°C)
On/Off	Single power button
Communications and serial port	Infrared communications link
	Cable communications link
Operating temperature	(-20°C to +65°C)
Channels	12 parallel, L1 C/A code and full carrier
Time to first fix	45 seconds
Warm start	15 seconds

Table 3
A sample of collected data

```
Spectrum® Survey 3.24                              VECTOR SUMMARY
VECTOR: alex1-ST2                         VECTOR OCCUPATION NO.: 01
----------------------------------------------------------------
Project:          D:\GPS paper\Paper.spr
Coordinate System:  UTM [Universal Transverse...]  Datum:          WGS84
Geoid Model:        <None>                   Units:          Meters
Processing Date:    2006/08/04 21:33:37 (UTC)
Ephemeris:        Broadcast                  Clock Model:     Broadcast
Elevation Mask:     5°
BASE STATION (alex1) [C:\...\Desktop\GPS obs\Gps(2-8-2006)\Alex1\07042141.str]
----------------------------------------------------------------
Point Occupation:       02
Antenna Height: 1.913 [Meas.: 1.916]   Antenna Model:   Stratus_Slant (meters)
Met. Measurements Used: Default        Dry Temp:        18.0 °C
Humidity:               50 %           Pressure:        1013.25 mbar
WGS84 (meters)               WGS84 (meters)
X:      4732329.795          Lat:  N 31 12 21.50599
Y:      2723847.327          Lon:  E 29 55 26.35565
Z:      3285478.601          Hgt:  60.795
UTM (meters)
E:       778596.210         Convergence:      1 30 57.39251
N:      3456114.569         Grid Scale Factor:    1.00055748
                         Elevation Factor:    0.99999045
REMOTE STATION (ST2)  [C:\...\GPS obs\Gps(2-8-2006)\Data of Site\07722146.str]
----------------------------------------------------------------
Point Occupation:       01
Antenna Height: 1.868 [Meas.: 1.871]   Antenna Model:   Stratus_Slant (meters)
Met. Measurements Used: Default        Dry Temp:        18.0 °C
Humidity:               50 %           Pressure:        1013.25 mbar
WGS84 (meters)                        WGS84 (meters)
X:      4731627.003     +/-  0.218   Lat:  N 31 12 37.04254      +/-  0.128
Y:      2724548.193     +/-  0.247   Lon:  E 29 56 02.54732      +/-  0.267
Z:      3285880.917     +/-  0.137   Hgt:  47.400                +/-  0.199
UTM (meters)
E:       779541.758     +/-  0.267   Convergence:      1 31 16.86101
N:      3456618.569     +/-  0.128   Grid Scale Factor:   1.00056399
                                  Elevation Factor:    0.99999256
VECTOR RESULTS
----------------------------------------------------------------
Solution Type: L1 float              Processing Interval:       1.00 second
Time Span:     2006/08/02 12:10:01.00 to 2006/08/02 12:12:01.00       [2 min.]
Observations: 968                    Observations Used: 956        [98.76%]
WGS84 Vector (meters)                   WGS84 (meters)
dx:     -702.793          +/- 0.2183   Slope:         1070.976      +/-  0.246
dy:      700.866          +/- 0.2468   FwdAz:   63 27 26.40037
dz:      402.316          +/- 0.1369   BwdAz:  243 27 45.15303
                                  FwdVA:   90 43 17.14998
RMS    0.004 (m)                   BwdVA:   89 17 17.48461
                                  dHgt:           -13.395
UTM (meters)
Grid Distance:            1071.484
Grid Azimuth:         61 56 28.65015
Vector Comb. Factor:      1.00055223
COVARIANCE MATRIX
----------------------------------------------------------------
            dx                    dy                    dz
dx     4.766924e-02
dy    -1.575486e-02      6.089333e-02
dz     7.636520e-03      3.471089e-03      1.873330e-02
----------------------------------------------------------------
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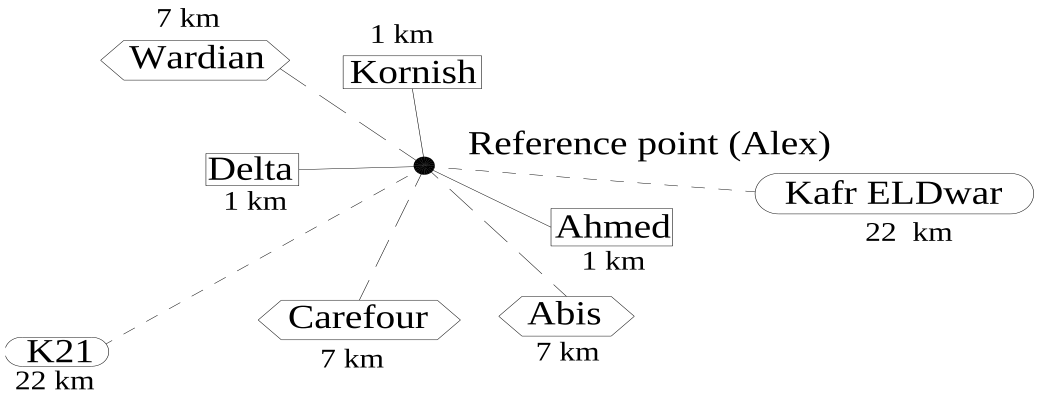

Fig. 1. Net sketch of the points' sites.

standard for comparison. Four factors were changed to study the effect on the accuracy and assess the use of single frequency receiver; these factors are baseline length, duration, mask angle, and interval.

Relations among the above mentioned four parameters were studied using graphical plots by fixing one parameter and changing the other three in turn to study their effect each time. The ordinates (y) in all plots are grid difference between single and dual frequency values which represent accuracy of the tested instrument. Only representative samples of these plots are shown here.

The relation between differences and duration for stations Ahmed, Delta and El Kornish are shown in figs. 2- 6 for intervals 1, 5, 10, 15 and 30 seconds respectively. These figures represent accuracy versus duration for short range.

The relation between differences and duration for stations Abis, after Carefour, and Al Wardian are shown in figs. 7- 11 for intervals 1, 5, 10, 15 and 30 seconds respectively. These figures represent accuracy versus duration for medium range.

The relation between differences and duration for stations Kafr El Dwar and K21 are shown in figs. 12- 16 for intervals 1, 5, 10, 15 and 30 seconds respectively. These figures represent accuracy versus duration for long range.

By studying the set of plots represented by figs. (2 through 16), It can be easily seen that stable and accurate results of a few millimeters are obtained for measurement session duration of 25 minutes: With less durations the accuracy reaches up to 60 cm, whereas with longer durations no appreciable improvement in accuracy is obtained. The accuracy increases as the interval decreases, and the differences decrease as the duration increases. It is believed that the two sites Elkornish, and Al Wardian have unreasonable results because of the error of multi-path.

5. Conclusions

Assessment of the Stratus single frequency receiver using dual frequency receiver as a standard for comparison in relative point positioning has been considered here. GPS users are seeking to achieve geodetic precision. Geodesists and surveyors have confidence in dual frequency receiver to achieve this precision. However, dual frequency receivers are much more expensive than single frequency receivers. The results of this study proved that relative point positioning using single frequency receivers realized a reasonable precision of a few millimeters in baseline measurement provided that proper conditions are satisfied. The optimum parameter values for such conditions are: 25 minutes for measurement duration; 15 degree for mask angle 5 second for interval between measurements. Importance of the factor of duration should be emphasized: Longer values are waste and smaller values cause degradation in accuracy.

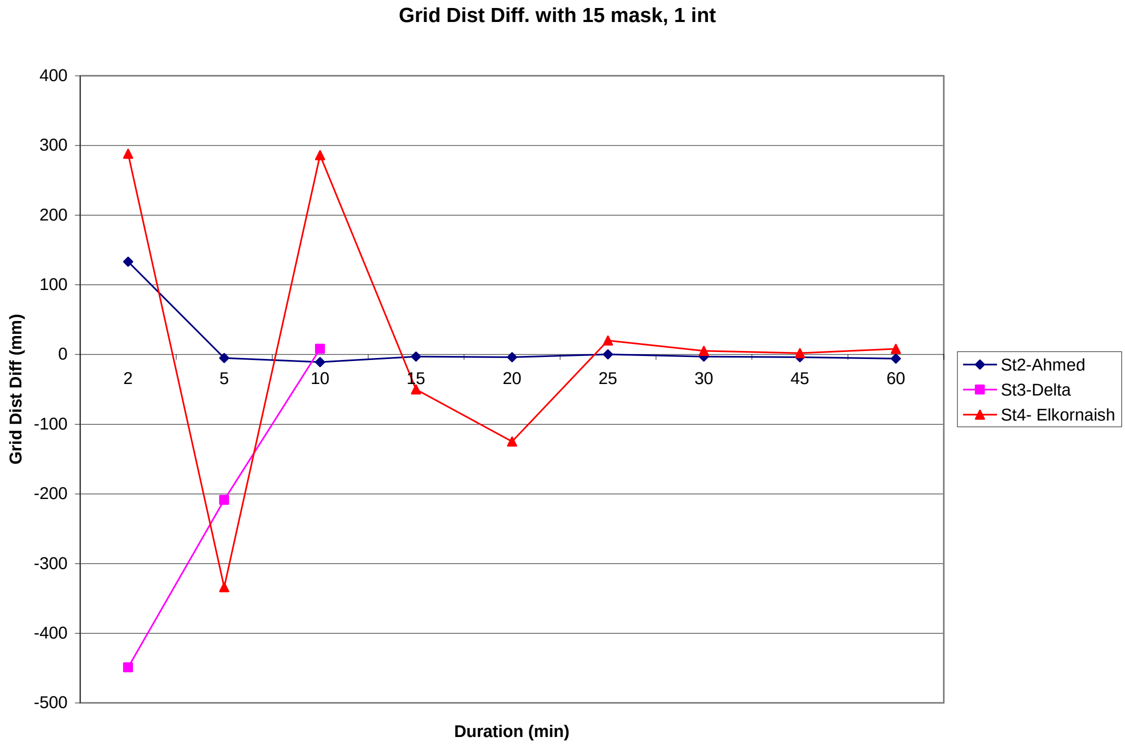

Fig. 2. Accuracy versus duration / short ranges for 1 sec interval.

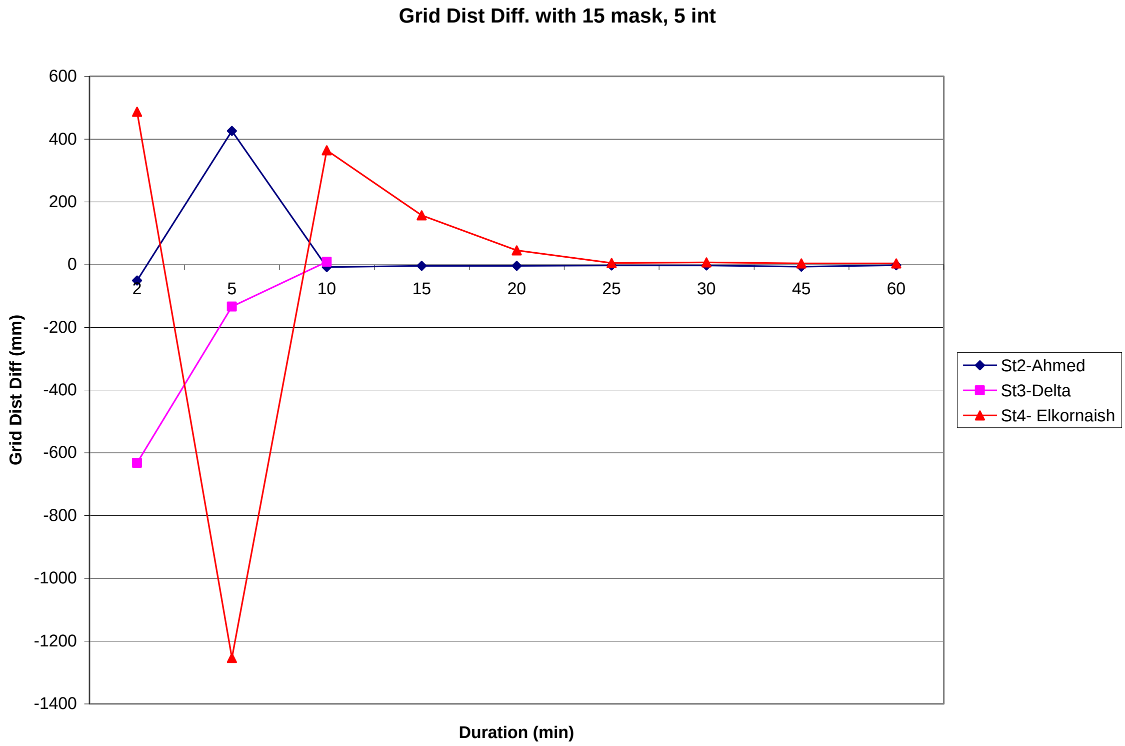

Fig. 3. Accuracy versus duration / short ranges for 5 sec interval.

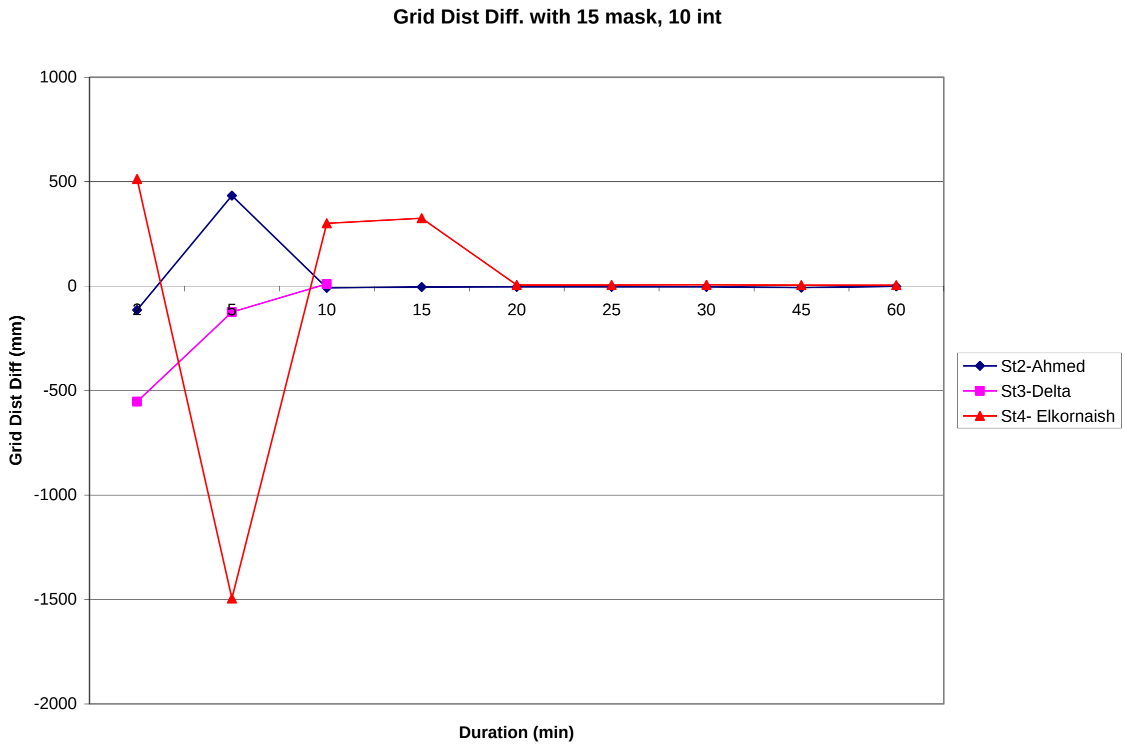

Fig. 4. Accuracy versus duration / short ranges for 10 sec interval.

Fig. 5. Accuracy versus duration / short ranges for 15 sec interval.

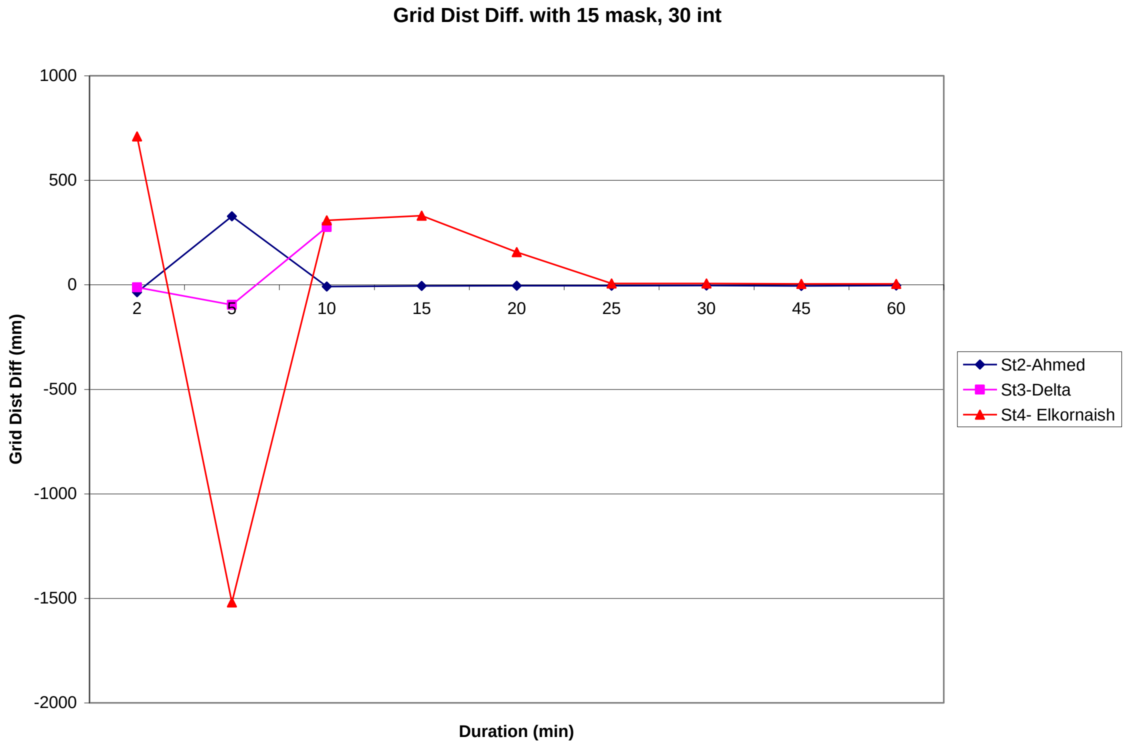

Fig. 6. Accuracy versus duration / short ranges for 30 sec interval.

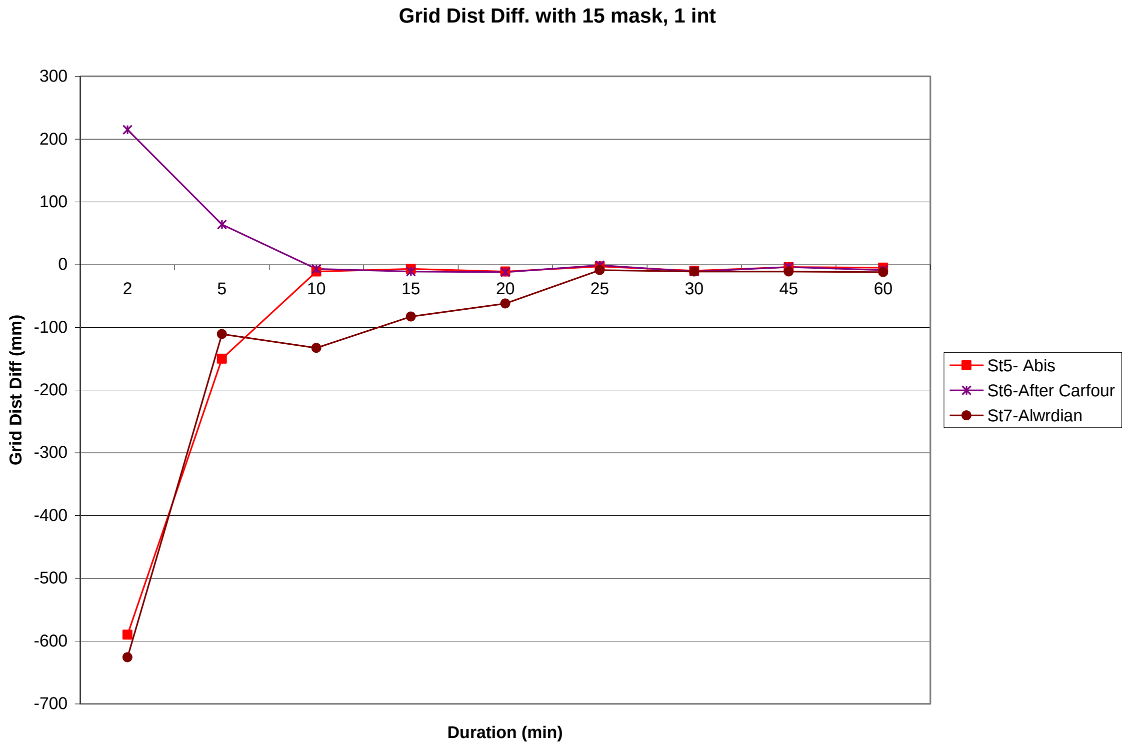

Fig. 7. Accuracy versus duration / medium ranges for 1 sec interval.

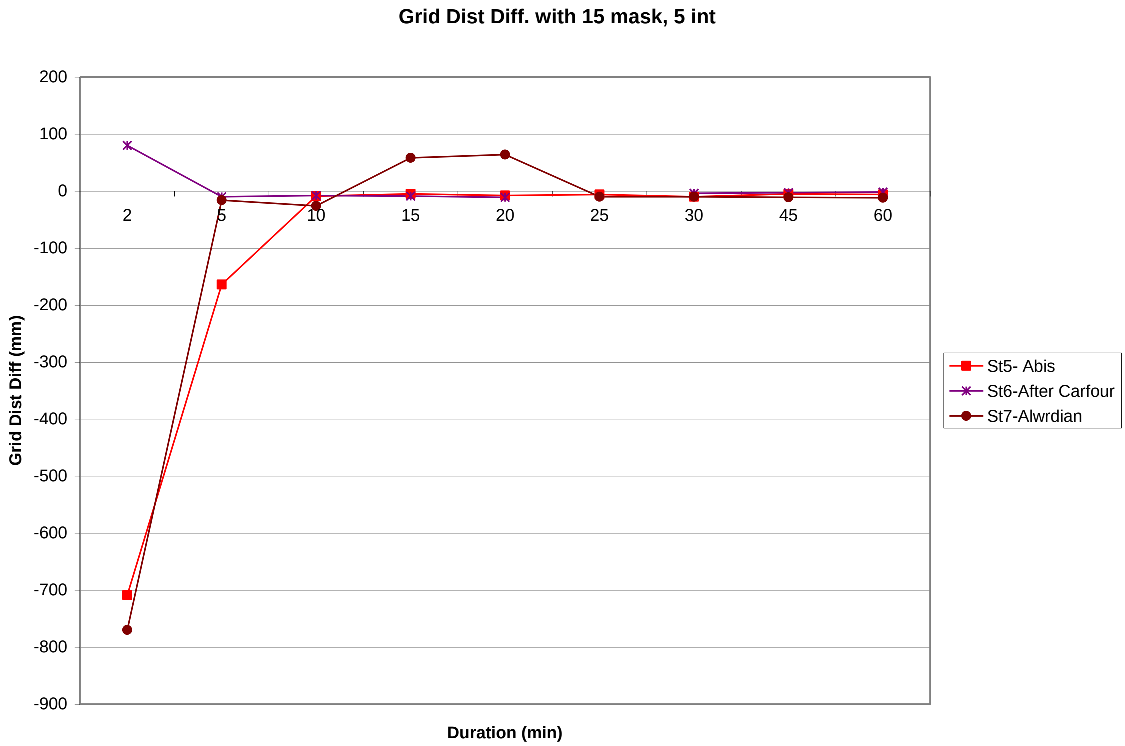

Fig. 8. Accuracy versus duration / medium ranges for 5 sec interval.

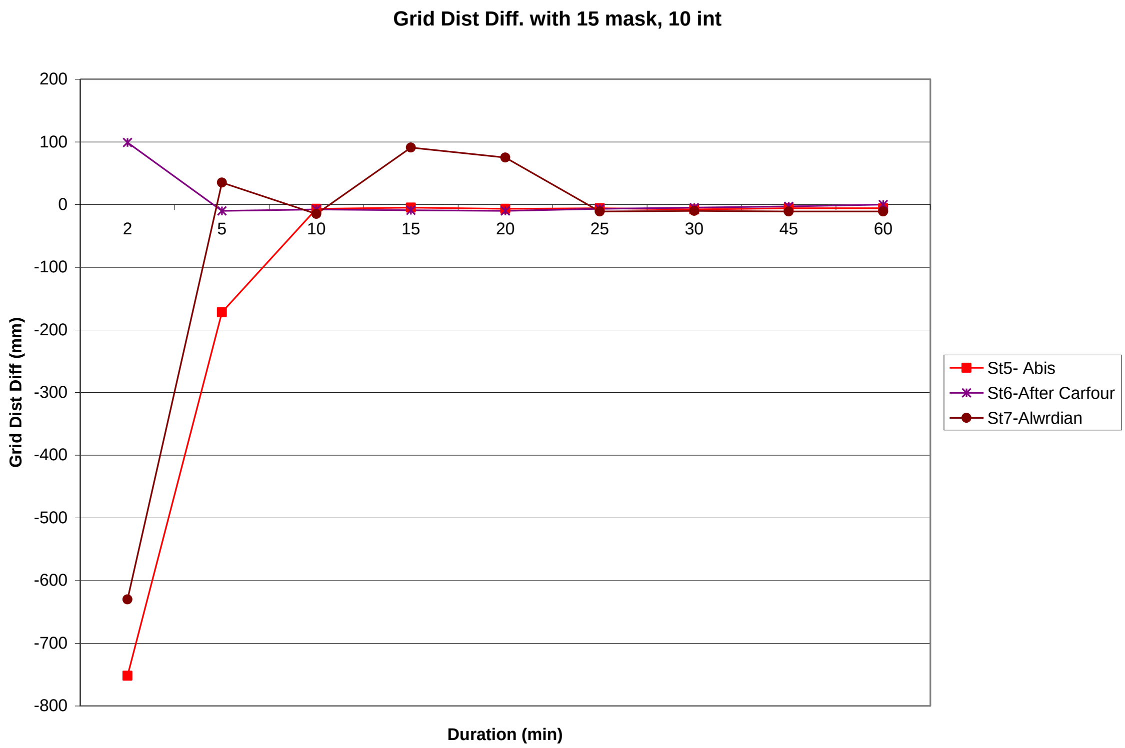

Fig. 9. Accuracy versus duration / medium ranges for 10 sec interval.

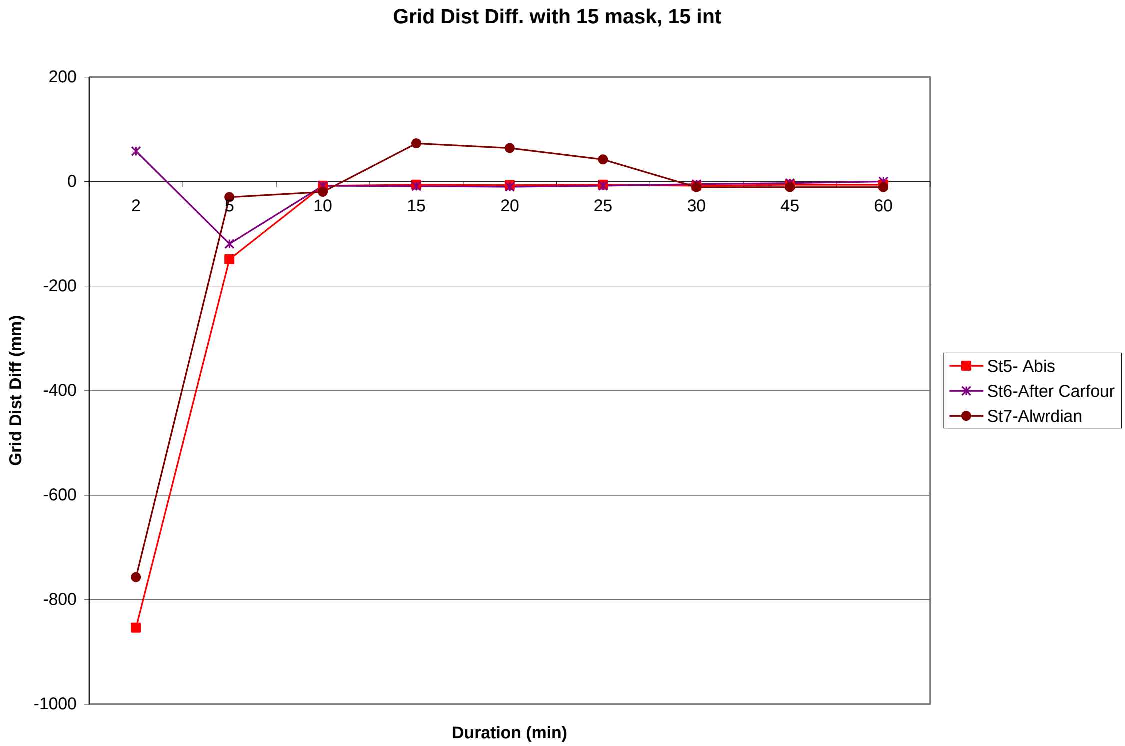

Fig. 10. Accuracy versus duration / medium ranges for 15 sec interval.

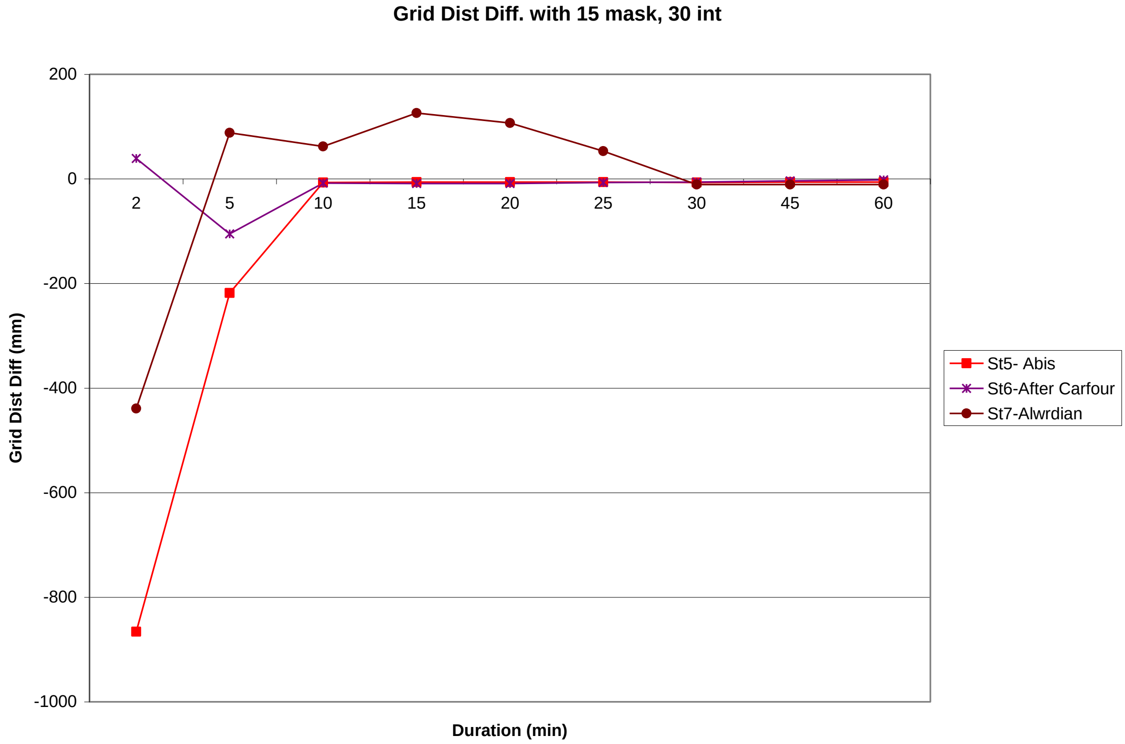

Fig. 11. Accuracy versus duration / medium ranges for 30 sec interval.

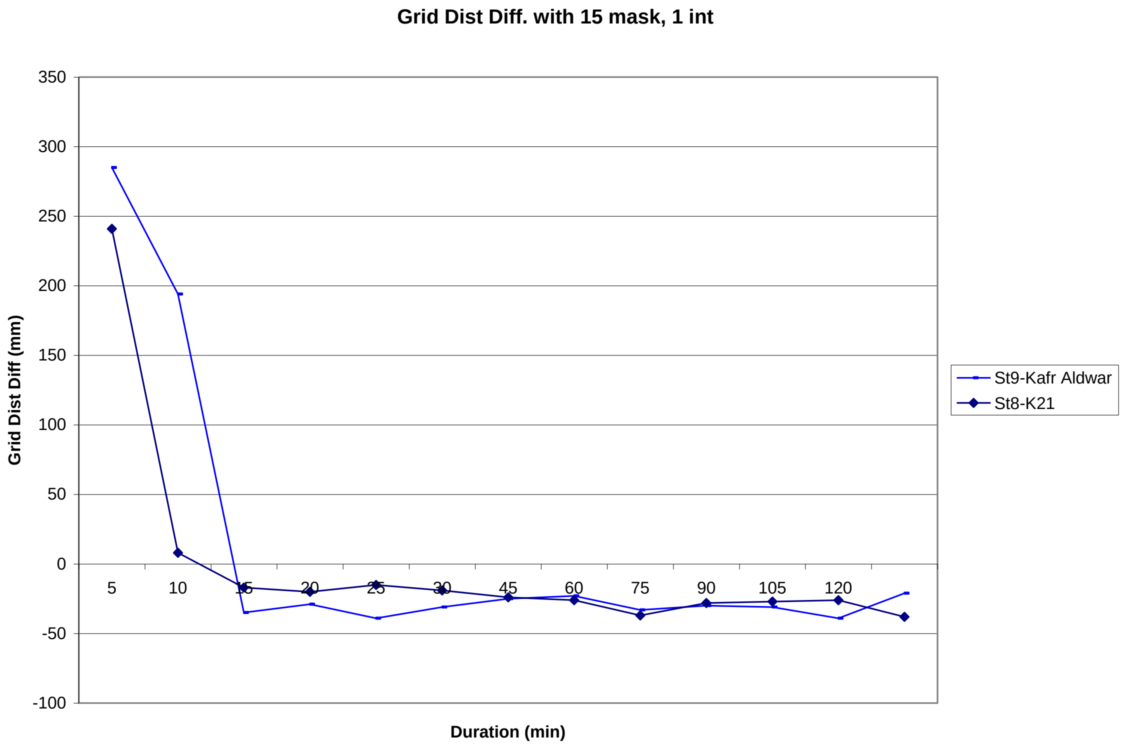

Fig. 12. Accuracy versus duration / long ranges for 1 sec interval.

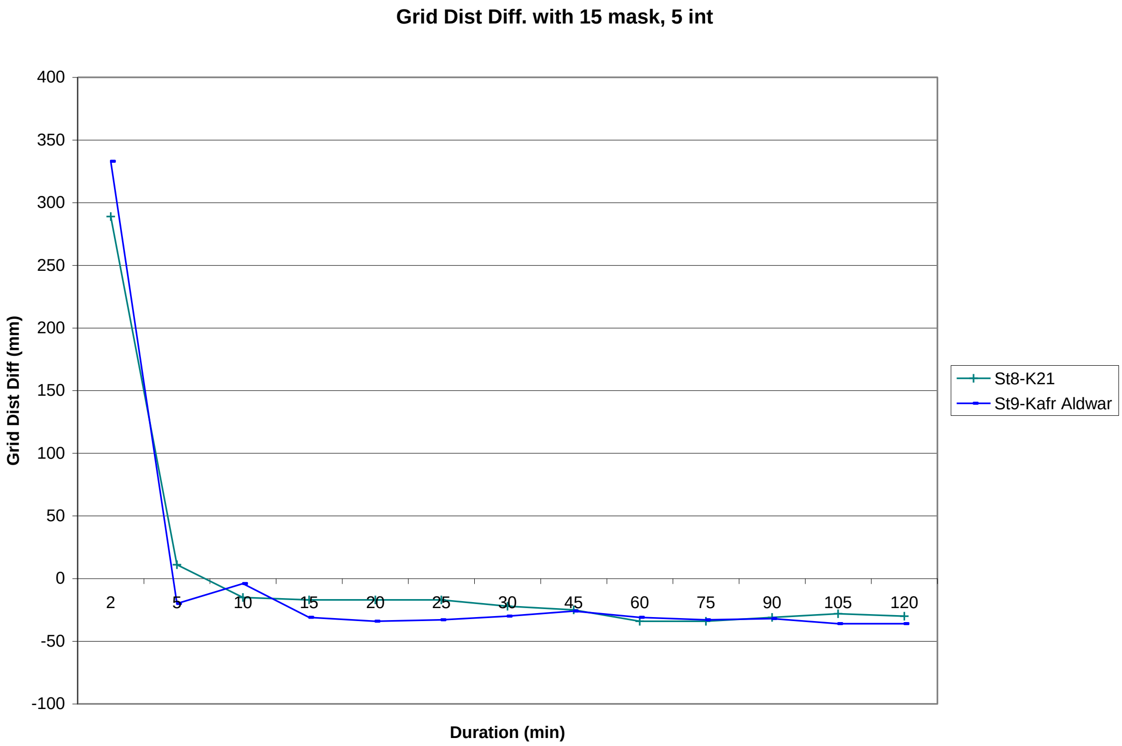

Fig. 13. Accuracy versus duration / long ranges for 5 sec interval.

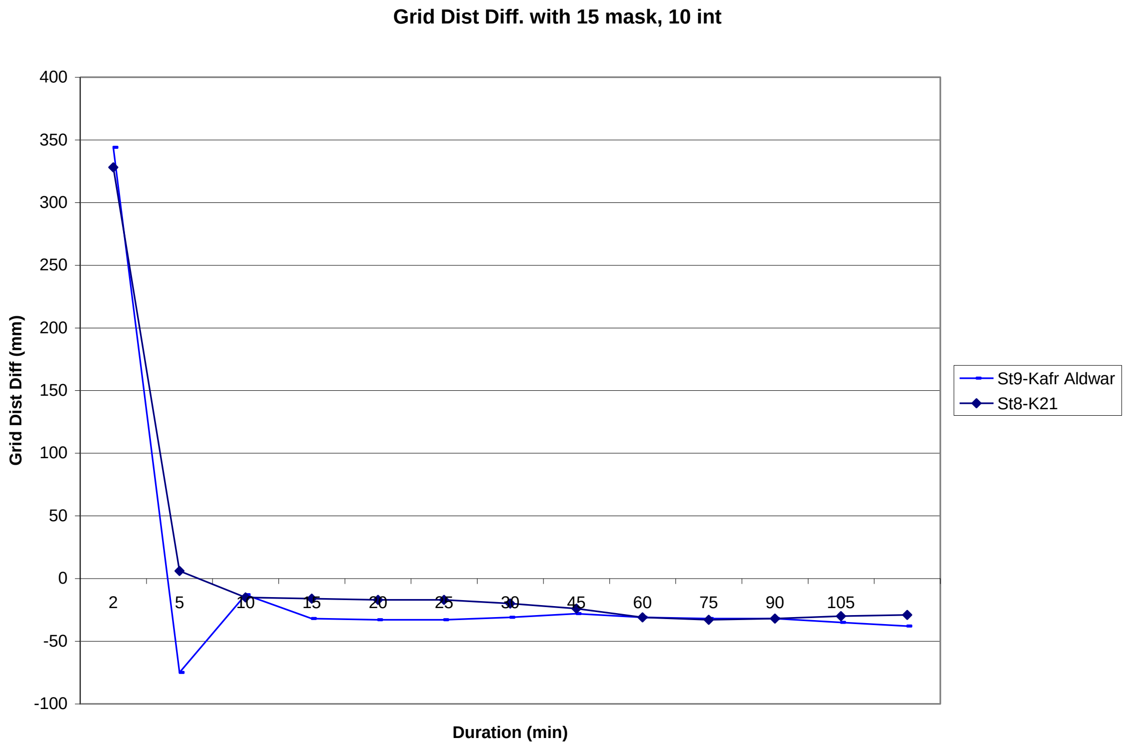

Fig. 14. Accuracy versus duration / long ranges for 10 sec interval.

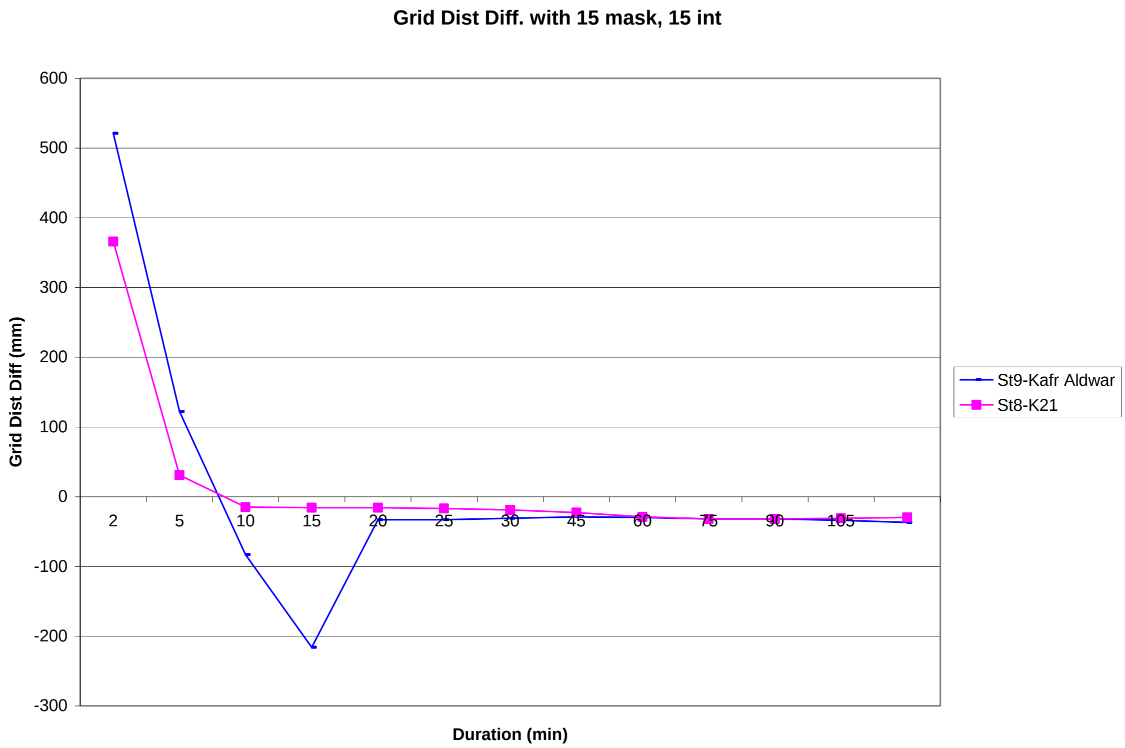

Fig. 15. Accuracy versus duration / long ranges for 15 sec interval.

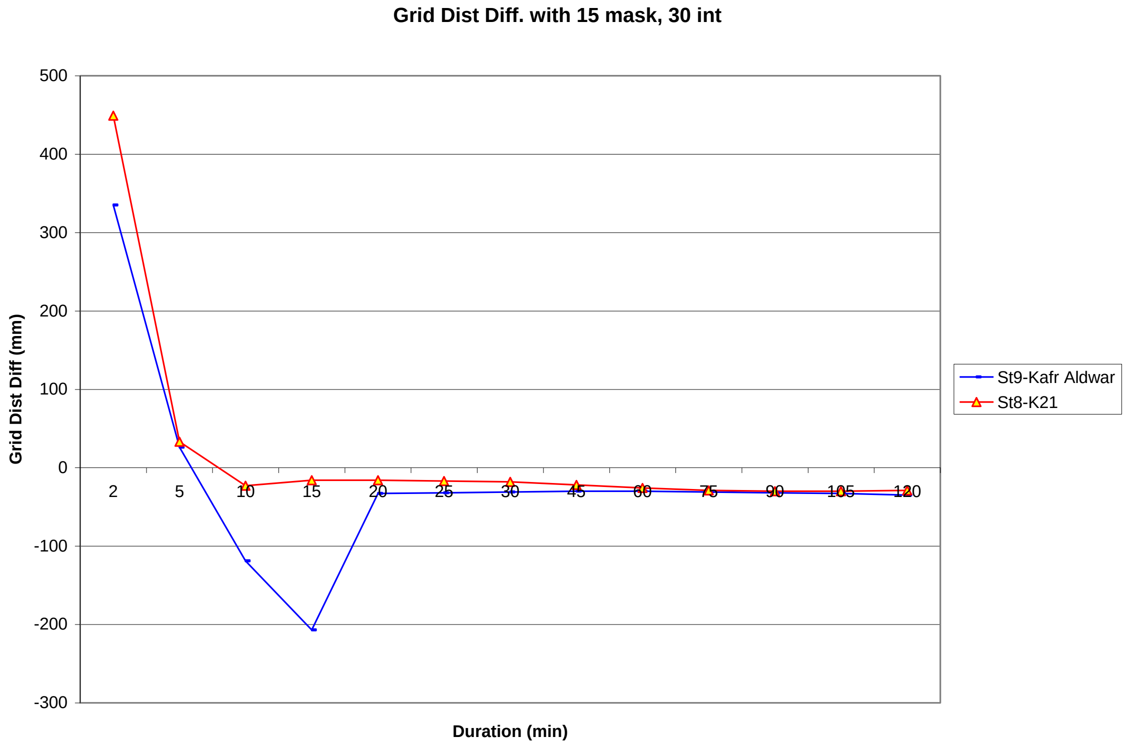

Fig. 16. Accuracy versus duration / long ranges for 30 sec interval.

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