ESTABLISHMENT OF PRECISE GEODETIC NETWORK FOR AL AIN REGION

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ABSTRACT:

Al Ain Town Planning Department established a precise geodetic network for the eastern region of Abu Dhabi Emirate. The network is considered to be as a basis and a development guide for governmental and private sector activities in the field of spatial data and mapping information, and also laid foundation for the implementation of Geographic Information System in the region.
The geodetic network is tied to the ITRF system, containing 35 well-distributed geodetic control stations. The paper outlined the quality of both of Al Ain Primary Geodetic Network (APGN) and Al Ain Secondary Geodetic Network (ASGN) referenced to ITRF datum. The accuracy for APGN was found to be 0.5 cm in latitude and longitude and 1.5 cm in height, and the corresponding accuracy of ASGN was 2cm in latitude and longitude and 3 cm in the height component.

1. INTRODUCTION

As part of the Updating of Al Ain geodetic network, topographic and Utility Maps of the eastern region of Abu Dhabi Emirates, Al Ain Town Planning Department (AATPD) established a very precise Geodetic Network known as Primary and Secondary Geodetic Networks. The networks are part of the UAE national geodetic networks and tied to the International Terrestrial Reference Frame (ITRF) stations. The APGN comprising of 9 control stations distributed throughout the Eastern Region and tied to ITRF system. The ASGN was tied to the APGN and would form the common reference frame for further surveying and mapping activities of Al Ain Town Planning Department.

A reconnaissance survey was carried out in order to inspect the existing ground survey stations that could possibly be used for this network. The APGN were established using simultaneous observations with a minimum number of three well-distributed ITRF stations. Reconnaissance is also carried out in order to locate suitable positions for the establishment of the secondary geodetic stations. This resulted in a list of 26 locations that were adopted for the placement of monuments to form the Secondary Order Geodetic Network. With a planned density of stations some 30 kilometres apart, sites were located convenient to habitable villages, developing locations, and main communication routes. Nine of the previously established APGN stations were located within the Eastern Region and so were integrated into the ASGN to control the network. Therefore the final estimates of the ASGN station co-ordinates defined the regional geodetic datum tied accurately to the APGN, and thus ultimately to the ITRF.

The definitions of network and local accuracy standards for horizontal co-ordinates and ellipsoidal heights of the geodetic stations were as given in table (1).

Network Type	Local accuracy (90% Confidence)	Network Accuracy (90% Confidence)
APGN/ ASGN	≤ 0.05 m	≤ 0.08 m

Table 1. The APGN/ ASGN Local and Network Accuracy Standards

2. GPS OBSERVATION DATA

The APGN field campaign resulted in the successful observation of six suitable 24-hour common data sessions at the primary geodetic network stations (APGN), and three 12-hour common data sessions at the additional network stations. The results of GPS data sessions and the meteorological observations were collated. Initial examination of the data, revealed the common GPS data session times have the duration of about 24 hours. The ASGN field campaign resulted in the successful observation of twenty-four suitable 3-hour common data sessions at the Secondary Geodetic Network Stations (ASGN) and fifty-one 1½-hour common data sessions at stations of the old geodetic network previously established by TPD in the Eastern Region (ATGN). Initial examination of the data revealed the common GPS data session times used in the establishment of the ASGN network. For this purpose a sequence of processing steps that followed sound geodetic principles was finally realized:

- Six ITRF stations were used to determine the overall geodetic datum of the APGN.
- The sixteen APGN stations were adjusted on this basis using a free network solution.
- The twenty-six ASGN stations were adjusted by re-ferring to the co-ordinates of nine APGN stations located in the proximity of the ASGN.

One of the most important activities in the field is the careful measurement and documentation of the antenna heights. For all the APGN and ASGN points the antenna heights were measured true vertical, so no reduction of slant heights was necessary.

To obtain the correct link between the electronic phase centre inside the antenna and a physical reference point outside of the antenna, an antenna phase centre model has been used. For this purpose the phase centre models of the IGS respectively of the National Geodetic Survey (NGS) were applied. This antenna phase model fits to the antenna reference point, which is at the bottom of the preamplifier (Fig. 1). The finally used antenna heights are in correspondence to the antenna phase model (equation 1); they were computed by:

$$H_{Bern} = H_{Obs} - R \,. \tag{1}$$

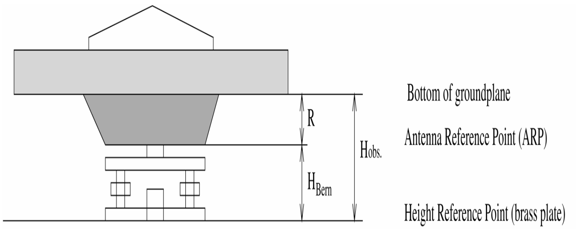

Figure 1. Reduction of true vertical antenna heights

The values "R" were taken from the antenna dimension file published by the IGS for example 5.6 cm for Trimble and 6.2 cm for Ashtech III antenna) or measured directly at the antenna Ashtech IIIA antenna with 6.05 cm. Supporting data for GPS processing such as precise ephemerides were acquired via on-line telecommunication techniques from IGS. Additionally, the Earth rotation parameters that belong to the final orbits were included (IGS9502.erp). This file also contains the values for UT1 - UTC that are accurate to approximately 50µseconds. For the integration of the orbits, one arc over 48 hours was computed. The arc ranged for each session from 00:00:00 UTC of the first day to 23:59:59 of the second day.

3. PROCESSING SOFTWARE

Final GPS data processing and adjustment was performed with the Bernese GPS software. The network analysis using Bernese Software is divided into three parts: Pre-analysis, Parameter estimation, and Final adjustment. **Pre-analysis** activities of the APGN and ASGN adjustment covered such aspects as data screening, cycle-slip screening, outlier detection and ambiguity resolution. For the ambiguity resolution the quasi ionosphere-free strategy was used. For this purpose an ionosphere model was included into the processing. Such ionosphere models are daily published by the Center of Orbit Determination in Europe (CODE); a single model covers a time span of two hours each. The satellite signal is on its way through the atmosphere also influenced by the Earth's troposphere. Modelling this influence in a representative manner would require recording of extended meteorological data. Within the applied **parameter estimation** for the APGN mainly the co-ordinates and troposphere parameters were estimated. Furthermore the normal equation files were created for every session. These normal equation files were combined in the **final adjustment**. In this manner several methods of fixing the geodetic datum were used and compared. The final combination gives the final co-ordinate file and the Variance–Covariance–Matrix of all co-ordinates.

4. ANALYSIS OF ITRF STATIONS

An analysis of station recordings revealed that the initially also envisaged the ITRF sites of Yerevan (NSSP) and Seychelles (SEY1) could unfortunately not be included in further processing since no data was available for the period of APGN observations. Furthermore it should be noted that there was a high degree of uncertainty for station Nicosia. The uncertainty referred mainly to the velocity value within the ITRF97 solution. These velocities are required to extrapolate the co-ordinates of the IGS stations from the solution epoch of ITRF97 (epoch 1997.0) to the epoch of the APGN campaign (epoch 2000.17). In order to obtain a further indication on the quality of ITRF station recordings a small study was carried out. For this study the observation data of several IGS stations were systematically analysed and adjusted. This led to the possibility of estimating the quality of observations on reference stations, and the results of co-ordinates o f the ITRF97. Another advantage of the study is the possibility of determining the data quality of the potential stations to be used for the link of the APGN to the global network.

Station	**North** [mm]	[mm]	**Height** [mm]
BAHR 24901M002	-2.5	1.0	7.8
IISC 22306M002	-6.4	6.9	9.4
KIT3 12334M001	-1.1	2.3	5.1
LHAS 21613M001	0.1	-0.1	-12.6
MALI 33201M001	14.0	-6.1	2.9
MDVO 12309M002	7.5	-14.7	11.1
NICO 14302M001	-11.6	10.7	-23.6
ANKR 20805M002 (*)	-15.0	-8.2	78.1
DGAR 30802M001 (*)	-44.3	-68.2	5.7
RMS_i [mm]	8.5	8.4	13.0
RMS_0 [mm]			11.6
Translation X [mm]			14.9 ± 4.4
Translation Y [mm]			-1.8 ± 4.4
Translation Z [mm]			33.0 ± 4.4
Rotation X ["]			0.0014 ± 0.0005
Rotation Y ["]			0.0009 ± 0.0005
Rotation Z ["]			0.0003 ± 0.0003
Scale [ppm]			0.0019 ± 0.0016

Table 2. Results of a 7-parameter transformation between constrained network and the ITRF97.

Due to the very high solar activity during the period of APGN observations the ionospheric disturbances lead to problems during the analysis of L1 and L2 observations. For solving phase ambiguities within the pre-analysis the observations on both phases L1 and L2 have been used. The parameter estimation itself has been carried out with a linear combination of the L1 and L2 observations, the so-called ionosphere free linear combination called L3. Within these L3 linear combinations the ionospheric delay is practically eliminated. In order to determine the quality of the different IGS Stations, firstly the co-ordinates of all stations were loosely constrained to a priori values. This had the advantage that the inner geometry of the network was maintained. Subsequently a 7-parameter transformation between the obtained set of co-ordinates and the official set of co-ordinates of the ITRF97 was carried out. The residuals for all stations are displayed in table (2).

The co-ordinates derived from the transformation exercise will now be compared to the ITRF values for Bahrain; this station is located rather close to the area under survey. This comparison provides an indication about the outer accuracy of the APGN network (Abdalla and Fashir 1997, Abdalla 2003, and Fashir et. al 1989), in other words the quality of the estimated co-ordinates within the ITRF97. According to table (3) the differences $X_{ITRF97} - X_{est}$ for Bahrain can be described with -2.5mm in the north, 1.0mm in the east, and 7.8mm in the height component. It is therefore realistic to assume that the ITRF97 is represented within the solution of the APGN to better than 1cm in east and north components and better than 1.5 cm in the height component. From the investigations, the stations BAHR, IISC, KIT3, LHAS, MALI and NICO were recommended for linking the APGN network to the ITRF (Hansa Luftbild 2000).

5. ADJUSTMENT OF APGN STATIONS

Al Ain Primary Geodetic Network (APGN) was adjusted by two different approaches [8]. In the first version, the co-ordinates of four fiducial APGN stations were held fixed and the remaining stations were referenced. In the second version, the APGN was adjusted using a free network solution. As a first step of adjustment the APGN network was linked to constrained ITRF stations and the fiducial network built of four APGN stations was linked to the six IGS (ITRF) stations as selected and shown in table (2).

An example of the base line configuration of the fiducial network is given in fig. (2). Configurations with different baselines were used for the several sessions, with “n” stations involved only “n-1” baselines can be defined for each session.

During the phase of pre-analysis, a strategy was made to solve the ambiguities. For the short baselines within the APGN it was possible to solve the ambiguities in the range of 50% to 90%. For the long baselines to the ITRF stations it was possible by this strategy to solve up to 50% of the ambiguities.
Modelling of the troposphere was realized for each station by estimating 6 tropospheric parameters for each 24 hours session, and 3 tropospheric parameters for each 12 hours session.

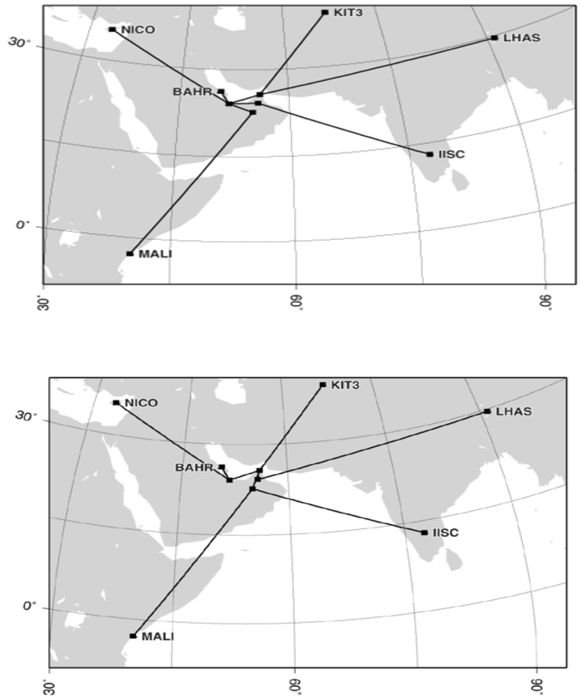

Figure 2. Baseline configurations for fiducial network

The co-ordinates of the four fiducial stations were adjusted by constraining the ITRF stations. The results achieved are shown in the following as repeatability of the individual session solutions, which provides an indication on the inner accuracy of the network. These repeatability values are generally also more realistic when judging the quality of the results since the covariance matrix tends to be too optimistic. The repeatability (RMS of individual session solutions and combined final solution) for the fiducial stations results are shown in Fig. (3) and found to be approximately 5mm for longitude and latitude, and approximately 12mm for the height component

In addition, the a priori co-ordinates of ITRF stations were loosely constrained. This meant that the inner geometry of the network would be maintained. Subsequently a 7-parameter transformation between the resulting set of co-ordinates and the official set of co-ordinates of the ITRF97 was carried out. The residuals at the six ITRF stations are displayed in table (3).

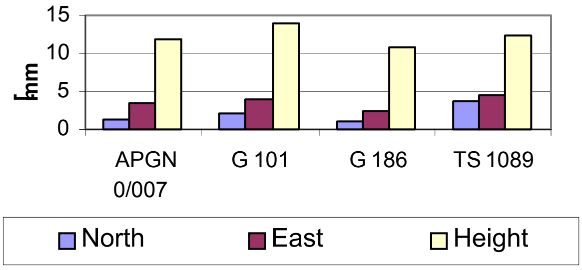

Figure 3. Repeatability of the fiducial network

Station	North [mm]	East [mm]	Height [mm]
BAHR 24901M002	0.6	-7.0	11.8
IISC 22306M002	-6.1	13.7	8.2
KIT3 12334M001	0.8	-4.9	6.4
LHAS 21613M001	0.8	-0.5	-13.6
MALI 33201M001	14.2	-2.7	-4.6
NICO 14302M001	-10.3	1.5	-8.2
RMS_i [mm]	8.3	7.4	10.2

Table 3. Residuals of a 7-parameter transformation between the loosely constrained adjustments

Al Ain Primary Geodetic Network (APGN) was adjusted in two different approaches. In the first version the previously determined co-ordinates of the fiducial solution were held fixed. The resulting repeatability of most of the APGN stations corresponds to results of geodetic networks of similar shape and size. are approximately 2mm for the north and east, and 5mm for the height component.

In the second version the APGN was adjusted using a free network adjustment. The advantage of a free network adjustment is the possibility to define the geodetic datum problem with minimum a priori information. For the free network adjustment in total 7 transformation parameters (3 translations, 3 rotations and 1 scale factor) were estimated with reference to an a priori network. The a priori network built by the four fiducial APGN points with their corresponding ITRF97 co-ordinates (Hansa Luftbild 2000).

The resulting repeatabilities can be indicated with better than 5mm in the east and north, and with better than 1cm in the height component when referring to all stations. For most of the stations the free network adjustment produced repeatabilities of approximately 2mm for the north and east component, and approximately 5mm for the height component.
When comparing the co-ordinate results of both adjustment strategies, thus the version with constrained fiducial points in comparison to the free network adjustment, the differences are less than 1mm. In an additional comparison the co-ordinates of the loosely constrained fiducial APGN points were transformed and compared to the results of the fiducial adjustment using fixed ITRF stations.

The obtained residuals are less than 1mm (table 4). This indicates that there is indeed no deformation existing within the network while fixing the fiducial points. Since the different adjustment strategies resulted in only very small co-ordinate differences it is recommended that the results of the free network adjustment is to be accepted as the final result. In conclusion, it can be summarized that the inner accuracy of the APGN is better than 5mm in longitude and latitude, and better than 10mm in its height component. The overall accuracy of the APGN network with reference to the ITRF97 datum can be interpreted as approximately 5mm in latitude and longitude, and approximately 15mm in its height component.

Station	North [mm]	East [mm]	Height [mm]
APGN 0/007	0.0	-0.1	-0.7
G 101	-0.1	0.0	0.0
G 186	0.0	0.1	0.4
TS 1089	0.1	0.0	0.4
RMS_I	0.1	0.1	0.5

Table 4. Residuals of 7-parameter transformation the APGN network and the fiducial networks

6. ADJUSTMENT OF ASGN STATIONS

Al Ain Secondary Geodetic Network (ASGN) was adjusted in the first version with reference to the previously determined co-ordinates of the APGN Network that was held fixed. In the second version the ASGN was referenced using a free network adjustment. In both solutions an a-priori sigma of $\sigma = 3$ cm for the estimated points was set. This was advisable since the ASGN network was composed of 8 sub-networks, which were in some cases linked by the estimated stations themselves.

In order to check for the internal quality and consistency of the data set a loosely constrained adjustment of the ASGN was firstly carried out. The results of this exercise were then transformed to the version that used fully constrained APGN station co-ordinates. The resulting residuals were at the level of 5mm for the planimetric components and at 15mm level for the height component. The repeatabilities of the majority of ASGN stations in the version with constrained APGN stations correspond to results of Secondary Geodetic Networks of similar shape and size. They are approximately 2cm for the north and east, and better than 3cm for the height component.
The quality of adjustment was also be independently verified at the checkpoint and the residuals are less than 1cm for the horizontal and 1.5cm for the vertical components, which indicates that the ASGN result is consistent with the APGN result.

7. CONCLUSIONS AND RECOMMENDATIONS

Al Ain regional geodetic networks are considered to be as a basis and as a development guide for typical governmental activities such as improving infrastructure, developing rural regions, building new settlements, and so forth. Moreover, building and maintaining this geodetic network lays the foundations for georeferencing and Geographic Information Systems, which are powerful tools for all kinds of governmental authority planning activities now and in the future. To meet the standards and specifications of spatial data, Al Ain Town Planning Department established primary and secondary geodetic control network for the eastern region of Abu Dhabi Emirate.

The processing and adjustment of the GPS observations are carried out with Bernese GPS software, the paper outlined the computation work carried out in this respect. In order to obtain the final set of APGN co-ordinates a free APGN network adjustment was computed and constrained to the six most suitable stations of the International Terrestrial Reference Frame (ITRF) located in the vicinity of the UAE.

The resulting inner accuracy of the network, the so-called local accuracy, has been achieved to approximately 0.5cm in longitude and latitude, and 1cm in height. The outer accuracy of the network, that means the accuracy of the geodetic link to the global datum of the ITRF97, has been achieved to approximately 1cm in longitude and latitude, and 1.5cm in height. Several analyses of a different nature that were carried out confirmed the given accuracies.

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