Realization of Dubai Emirate Datum on the Reference Frame 2000

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Key words:

SUMMARY

With The growing capabilities of GPS as a high precision positioning system for surveying and mapping and to keep pace with the technology the Dubai municipality (DM), Dubai UAE, established FIVE GPS reference stations called Dubai Virtual Reference System (DVRS) which operate continuously for 24 hours a day. To define these stations precisely on International Terrestrial Reference Frame 2000 (ITRF2000), DM in cooperation with University Technology Malaysia (UTM) has derived the precise coordinates of these five stations on ITRF2000.

Dubai GPS Network control, which was connected to the ITRF-93 reference frame, is being used in the Emirate for surveying activities and followed by the establishment of DVRS. Originally these station coordinates are defined on the ITRF-93 frame. Now the transformation parameters are calculated between the two reference frames.

The data from five (5) DVRS stations together with eight (8) IGS stations from weeks 1160 to weeks 1177 have been used in the preliminary data processing and for statistical analysis. The eight (8) IGS stations surrounding Middle East have been included in the processing in order to determine the DVRS stations coordinates on ITRS2000 reference frame. To get high precision results the Bernese GPS processing software version 4.2 was used.

There were pre-processing for daily and weekly solutions, the rms error for the triple-difference was around 1.5cm. A total of 18 weekly solutions were taken for network adjustment. A posteriori sigma of unit weight of 0.0017m was achieved. The accuracy of DVRS stations with respect to the IGS2000 reference frame is of the order of 6-13 mm in the horizontal component and 15mm in height. Helmert transformation parameters were derived between ITRF93 and ITRF2000.

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1. INTRODUCTION

The Survey Section of Dubai Municipality successfully established GPS Network in the ITRF-93 reference frame and extensively it was used for all Geodetic Topographical and cadastral purposes till today and followed by the establishment of Dubai Virtual Reference System (DVRS) in 2001. With the growing capabilities of GPS as a high precision positioning system for surveying and mapping and its varied application in the scientific field made the department to keep update the reference frame ITRF93 to ITRF2000. This is carried out through DITRF2000 Project by Survey section under supervision of UNI-Technologies SDN. BHD company of Universiti Teknologi – Malaysia . It is decided that the DVRS stations capturing continuous data will be taken for computation along with other IGS stations and the ITRF93 stations and parameters will be derived between ITRF93 and ITRF2000 coordinate.
At present five (5) VRS stations operating continuously for 24 hours a day. With the growing capabilities of GPS as a high precision positioning system for surveying and mapping there is a necessity for the DVRS stations to be defined on the precise reference system such as International Terrestrial Reference System (ITRS) that managed the International Terrestrial Reference Frame (ITRF).

2. DATA ACQUISITION

The data from five (5) DVRS stations together with eight (8) IGS stations from GPS weeks 1160 to weeks 1177(for 4 months – 17 weeks) have been used in the preliminary data processing and for statistical analysis.

2.1 DVRS Data

Summary of GPS receivers and associated antennas used in the DVRS stations are tabulated in Table 1 and stations distribution as in Figure 1.

No.	Station	Station ID	Receiver	Antenna	Ant. Height (m)
1	Cattle Market	DRS1	LEICA	LEIAT504_SCIS	1.516
2	Lu Say Li	DRS2	LEICA	LEIAT504_SCIS	0.516
3	Marqab	DRS3	LEICA	LEIAT504_SCIS	0.516
4	Shk. Zayed Road	DRS4	LEICA	LEIAT504_SCIS	0.516
5	Hatta	DRS5	LEICA	LEIAT504_SCIS	1.516

Table 1: Receiver and antenna type for DVRS station

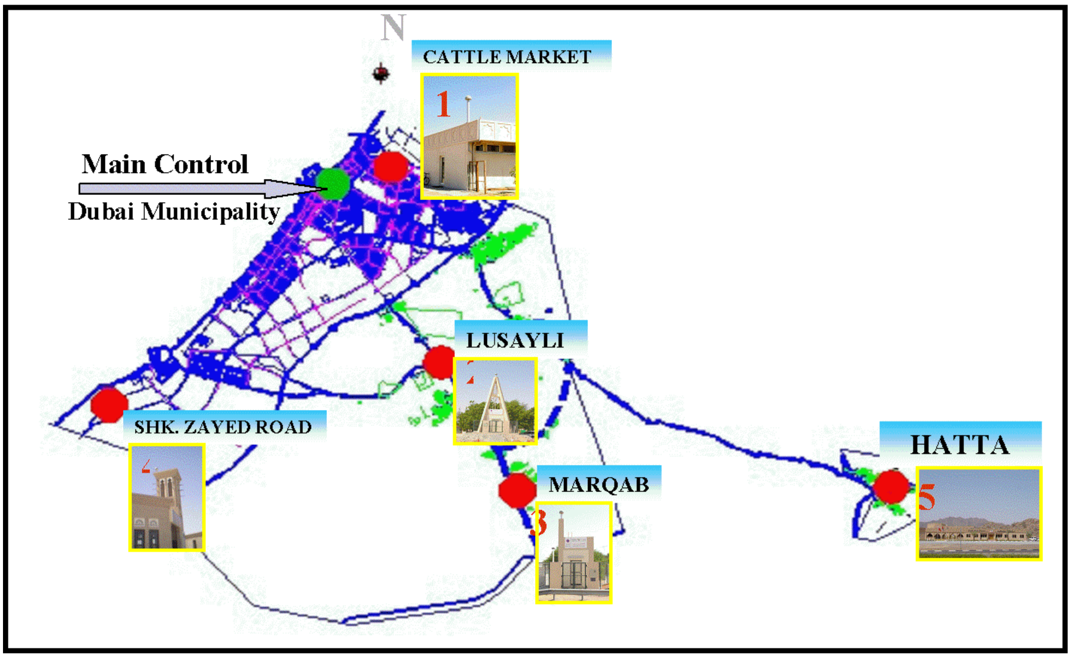

Figure 1: DVRS Stations Distribution

2.2 International GPS for Geodynamic Services (IGS) Data

Eight (8) IGS stations surrounding Middle East have been included in the processing in order to determine the DVRS stations coordinate on ITRS reference frame, Ammn in Jordan is a new IGS station and the coordinates is not listed yet. The list of IGS stations is shown in Table 2.

No.	Station Id	Station Name	Country
1	MATE	Matera, Telespazio S.p.A.	Italy
2	KIT3	Kitab, Ulugh Beg Astro. Institute	Uzbekistan
3	MALI	Malili, ESA / ESOC	Kenya
4	LHAS	Lhasa, BKG	China/Tibet
5	IISC	Indian Institue of Science	India
6	BAHR	Bahrain GPS Station, NIMA	Bahrain
7	AMMN	Amman, Royal Jordanian Geographic Centre	Jordan
8	NICO	Nicosia-Athalassa	Cyprus

Table 2: IGS stations list

3. DATA PROCESSING

3.1 Software

The Bernese GPS processing software version 4.2 (Rothacher and Mervart, 1996) was used in the processing of five (5) DVRS stations together with eight (8) IGS stations. Bernese GPS processing software is developed by Astronomical Institute University of Berne, Switzerland. The software is one of the state-of-the art GPS processing package that widely use by universities or other agencies that need a high precision results. The software is also capable of computing the GPS baseline by using double differencing as well as un difference data (Precise Point Positioning).

3.2 Processing Strategy

The processing is automated using Bernese Processing Engine (BPE) that run on Red Hat Linux version 7.1, which facilitates the routine process. Basically the GPS data processing using Bernese Software can be divided into four parts; (1) Pre-processing, (2) Processing Part I , II , III and IV and (4) Weekly combination.

3.2.1 Pre-processing

The general principle in data pre-processing for daily solutions can be summarized as follows:

3.2.1.1 Orbit Computation

- IGS Final orbit referred to IGS00 have been used in all computation with IERS C04 series earth rotation parameter. Two programs associated to the orbit computation are PRETAB and ORBGEN.
- PRETAB programs compute a table of satellite positions in the inertial frame in J2000.0 system from the available orbit information i.e from the precise ephemerides that referred to the IGS00 frame. The programs also produce the satellite clock file that may be used to compute satellite clock corrections for each observation epoch.
- ORBGEN programs in general will produce what we call standard orbit with one or more standard arcs, each of which characterized by a start and end time. Ocean tides correction OT-SCRC model is introduced at this stage with development planetary ephemeris (DE200).
- The rms errors of 1 – 2 cm for each satellite have been achieved and this shows that the IERS C04 series of earth rotation parameter is consistent with the weekly pole information from the IGS final orbit.

3.2.1.2 Data Conversion

- Data conversion from Rinex to Bernese format is using the RXOBV3 programs. The output of the data conversion is four (4) files namely the code zero observation and header (*.CZO and *.CZH) and phase zero observation and header (*.PZO and *.PZH).
- The interval of observation data has been set to 30 second and this means that if the Rinex file used 5 or 15 second data interval the RXOBV3 programs will convert it into 30 second data sampling and save it in the bernese format.

3.2.2 Processing Part 1

3.2.2.1 Code Single Point Positioning (CODSPP)

- The main task of CODSPP program is to compute the receiver clock correction (denote as δ_k) with the accuracy of better than $1\mu_s$. It is possible to compute δ_k a priori with sufficient accuracy using zero-difference code measurements.
- The second task of CODSPP is the receiver coordinates. With SA active the normal rms error for coordinates is between 20 – 30 meter and with SA switch off the rms error around 3 m is expected. In order to reach an accuracy of $1\mu_s$ in δ_k it is necessary to have the code measurement with the rms error less than 300 m.
- CODSPP used the standard least-square adjustment to compute the unknown parameters. The observables zero-difference code measurement with L_3 (ionosphere-free) linear combination is used and a priori troposphere model relative to Saastamoinen models is applied. Other input is a priori coordinates files, standard orbit and satellite clocks files. The most important output of this program is to write the receiver clock correction (δ_k) in the code and phase zero difference for further computation.

3.2.2.2 Forming Single Difference Baseline (SNGDIF*)*

- The program SNGDIF creates the single-differences (between two receivers) and stores them in files. The programs create both code and phase single differences but for further computation only phase single differences will be used.
- The strategy used in forming the single-differences is SHORTEST method but if any stations recorded less data the pre-defined option will be implemented in order to keep the particular station as *end point*.

3.2.2.3 Phase Data Screening (MAUPRP)

- The phase data screening is using Manual Automatic Pre-Processing program (MAUPRP) and the main task is to screen the cycle-slips using L3 linear combination triple difference. The program will try to fix the cycle-slip and marked unpaired observation (L1 without L2 and vice-versa), small pieces of data, gaps and observations at low elevation and setup the ambiguities.
- The input for the program is the single difference baseline files, a priori stations coordinates with 1m accuracy and standard orbit.

- The recommended value for each panels are implemented with certain changes. The ambiguity setup for continuous observation is set for every 1800 second, data interval with less than 1800 second will be mark as a small piece and if the gaps are less than 91 second the data will be threat as continuous observation.
- The programs has to be run twice for each baseline in order to totally fixed all the slips as well as to marked the problems data (small pieces etc). The rms error for the triple-difference around 1.5 cm is achieved for all baselines.

3.2.3 Processing Part 2

3.2.3.1 Parameter Estimation (I) – Save Residuals

- The Bernese 4.2 new features are the capability of the used of ocean tide correction, estimated troposphere and mapping function. Prior to Version 4.0 the used of ocean tide loading is not possible as well as the troposphere mapping function.
- L3 linear combination has been used for the computation to check the post-fit residuals.
- The mapping function of the troposphere is using Dry-Niell and the cut-off angle is set at 10 degrees with elevation-dependent weighting was used.

3.2.3.2 Parameter Estimation (II) – Creating Ionosphere Models

- Creating ionosphere model is essential for the baseline longer than 500 km as recommended by AIUB. Experiment has been made for selected baseline to see the ionosphere variation for 24 hours observation. The geometric free linear combination L4 (L1 – L2) has been used for the estimation of ionosphere models.

3.2.3.3 Parameter Estimation (III) – Ambiguity Resolution

- Quasi Ionosphere Free (QIF) ambiguity resolution strategy has been used in all computation as recommended by AIUB. Other strategy such as Melbourne-Wubbena wide-lane technique has been tested over long baseline but the result is not as good as QIF strategy in term of resolved ambiguity.
- The average resolved ambiguity for the DVRS stations processing from GPS week 1160 - 1177 is around 85%.

3.2.3.4 Parameter Estimation (IV) – Daily Solution

- The daily solutions (session) of the independent baselines were loosely constrained with 1 m apriori sigma using L3 linear combination and no coordinates in the network adjustment were fixed and the daily normal equation stored. The resolved ambiguities from (3.2.3.3) were introduced in the computation.

3.2.4 Weekly Solution

- Weekly solution is the combination of seven (7) normal equations of the daily solution.
- Seven (7) IGS stations were held fixed with the coordinates transform to the middle of the week.
- Two strategies have been applied for the weekly solution adjustment and the strategies as follow:
  - Free Network adjustment with the introduction of Helmert Transformation
  - Heavily constrained
- Both results were analyse statistically and coordinate repeatability as well as the RMS of residuals were check.
- Bad coordinate solutions were excluded at this stage and the final weekly normal equation then stored with fiducially free network with 1meter apriori sigma for all coordinates.
- A total of 18 weekly solutions were available for the next computation.

4. FINAL COMBINED SOLUTION – STATISTICAL ANALYSIS

The final combined solution consists of 18 weekly solutions and 13 stations (8 IGS stations and 5 DVRS stations). Free Network with introduction of Helmert Transformation strategies has been made in order to have optimum results as well as to check any outliers in the final adjustment.

4.1 Free Network Adjustment

The general principle of free network adjustment with the introduction of Helmert Transformation is to adjust the weekly normal equation freely and later transform using seven (7) IGS stations (*Appendix A*). The parameters used in the adjustment as follows:

Reference Coordinates	IGS00
Reference Velocity	IGS00
Troposphere Sigma	5.0m/5.0m absolute/relative
Zenith Delay Interval	4 hours
# Helmert Parameter (Coordinates)	3/6
# Helmert Parameter (Velocity)	0
# Fixed Stations	7
# Normal Equation Files	18
# Parameters	24755
# Observations	5287489
# Single Difference Files	1215
A posteriori Sigma of Unit Weight	0.0017 m

Table 3: List of Parameters

With a short span of the data set, the velocity is not estimated in the combined solution. The reference coordinates for the IGS stations were fixed at 1 June 2002.
The RMS of residuals for individual stations are shown in *Table 4* and the graphical presentation is in *Figure 2*.

Station	North (mm)	East (mm)	Up (mm)
DVRS1	0.90	1.40	3.00
DVRS2	1.10	1.50	3.20
DVRS3	0.80	1.60	3.10
DVRS4	0.70	1.60	2.60
DVRS5	1.00	1.80	3.20

Table 4: RMS of Residuals (Unweighted)

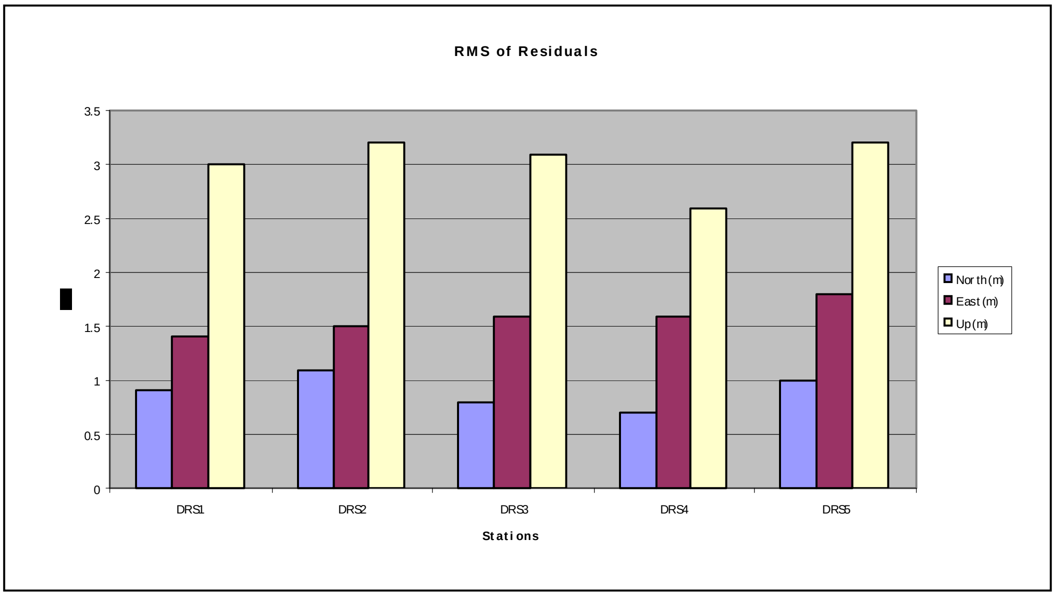

Figure 2: RMS of Residuals

From *Table 4* and *Figure 2*, it can be concluded that the internal accuracy of the DVRS stations from the free network adjustment is less than 2 mm in the horizontal component and less than 5.5 mm in the height component.
Comparison for IGS stations also have been made in order to determine the accuracy of the network with respect to the IGS stations. From *Figure 3* below, it shows that the residuals on each component are at mm and the RMS for individual component is 3.3 mm, 11.0 mm and 13.3 mm for the north, east and height component respectively.

It can be concluded that the accuracy for DVRS stations with respect to the IGS2000 reference frame within 6 to 13 mm in the horizontal component and 15 mm in height.

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HELMERT TRANSFORMATION
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FILE 1: COMBINED 18 WEEKS SOLUTIONS FREE SOL. COND
FILE 2: IGS00/ITRF00 COORDINATES BASED ON IGS01P37_RS54.SNX/ITRF2000_GPS

LOCAL GEODETIC DATUM: WGS - 84
RESIDUALS IN LOCAL SYSTEM (NORTH, EAST, UP)

---------------------------------------------------------------------
| NUM | NAME | FLG | RESIDUALS IN MILLIMETERS | |
---------------------------------------------------------------------
| | | | | |
| 213 | BAHR 24901M002 | N I | 1.1 8.7 -11.1 | |
| 163 | NICO 14302M001 | N I | -1.6 11.9 -17.5 | |
| 306 | MALI 33201M001 | N I | -0.4 -0.2 12.2 | |
| 209 | IISC 22306M002 | N I | 5.8 -12.9 -12.8 | |
| 144 | MATE 12734M008 | N I | -4.7 9.3 6.5 | |
| 136 | KIT3 12334M001 | N I | -1.6 -0.7 14.5 | |
| 205 | LHAS 21613M001 | N I | 1.3 -16.1 8.2 | |
| | | | | |
---------------------------------------------------------------------
| | RMS / COMPONENT | | 3.3 11.0 13.3 | |
---------------------------------------------------------------------
NUMBER OF PARAMETERS : 6
NUMBER OF COORDINATES : 21
RMS OF TRANSFORMATION : 11.1 MM

PARAMETERS:

TRANSLATION IN X : 0.0 +- 4.2 MM
TRANSLATION IN Y : 0.0 +- 4.2 MM
TRANSLATION IN Z : 0.0 +- 4.2 MM
ROTATION AROUND X-AXIS: - 0 0 0.0005 +- 0.0004 "
ROTATION AROUND Y-AXIS: - 0 0 0.0008 +- 0.0005 "
ROTATION AROUND Z-AXIS: - 0 0 0.0000 +- 0.0003 "

NUMBER OF ITERATIONS : 2
```

Figure 3: IGS Coordinates Comparison

4.2 Time Series

Results from final free network condition adjustment (with all available data set – 24 weeks) will be made and analyzed for the time series. Time series analysis for 24 weekly solutions will be made into two parts with the first part is the weekly coordinates repeatability with respect to the combined solution daily coordinates repeatability for the later part.

5. ADJUSTED COORDINATES

The adjusted coordinates from the free network condition adjustment are referred to the 1 June 2002 and the coordinates are listed as in *Figure 4.*

```
Num Station Id Coordinates Component RMS

603 DRS1 X 3277208.6069 0.0001
 Y 4749644.0761 0.0002
 Z 2707717.1811 0.0001

 HEIGHT -21.3074 0.0003
 LATITUDE 25 17 8.594514 0.0001
 LONGITUDE 55 23 40.915639 0.0000

 604 DRS2 X 3319217.2714 0.0001
 Y 4741062.5522 0.0002
 Z 2671617.8228 0.0001

 HEIGHT -8.5351 0.0002
 LATITUDE 24 55 32.823600 0.0001
 LONGITUDE 55 0 14.902802 0.0000

 605 DRS3 X 3278838.6452 0.0001
 Y 4764817.8836 0.0002
 Z 2679336.3436 0.0001

 HEIGHT 67.8290 0.0002
 LATITUDE 25 0 8.362749 0.0000
 LONGITUDE 55 28 0.383241 0.0001

 606 DRS4 X 3274290.1397 0.0001
 Y 4778425.9625 0.0002
 Z 2660937.2772 0.0001

 HEIGHT 157.1452 0.0002
 LATITUDE 24 49 7.732528 0.0001
 LONGITUDE 55 34 48.498795 0.0000

 607 DRS5 X 3228235.6245 0.0001
 Y 4809892.7029 0.0002
 Z 2660835.2036 0.0001

 HEIGHT 289.9841 0.0002
 LATITUDE 24 49 2.081327 0.0001
 LONGITUDE 56 7 54.615708 0.0000
```

Figure 4: IGS2000 Coordinates (RMS is the formal accuracy)

6. CONNECTION TO ITRF93

In 1995 during the DUREF-95 GPS campaign between Dubai Municipality and IfAG (BKG) undertaken the GPS observation and computation, in order to connect the Dubai Geodetic Network to International Terrestrial Reference System (ITRS) ITRF93. Four stations from the DUREF-95 have been re-observed simultaneously with the DVRS station on 11th May

2002 for six hours. With the connection the helmert transformation parameters can be derived in order to established the relationship between ITRF93 and ITRF2000 coordinates.

6.1 Data Processing'

The GPS data was processed using Bernese 4.2 software with the strategy similar to the DVRS permanent stations (Para 3.2) processing. Five (5) DVRS station processed together with four (4) established triangulation station (ITRF93) namely ET145, ET228, OBP5 and ET152 and the results (*Appendix B*) shows that it of high quality.

Num	Station	Par.	ITRF93 Coordinates	RMS	IGS2000 Coordinates	RMS
1	ET145	Latitude	24° 56′ 29″.091655	.0002	24° 56′ 29″.100200	.0002
		Longitude	55° 14′ 06″.394970	.0003	55° 14′ 06″.402339	.0002
		Height	33.9275 m	.0011	33.8377 m	.0019
2	ET228	Latitude	25° 15′ 52″.526020	.0002	25° 15′ 52″.534672	.0002
		Longitude	55° 18′ 43″.449964	.0003	55° 18′ 43″.458036	.0002
		Height	2.7387 m	.0011	2.6679 m	.0013
3	OPB5	Latitude	25° 12′ 36″.474185	.0002	25° 12′ 36″.482736	.0002
		Longitude	55° 37′ 45″.625708	.0003	55° 37′ 45″.633848	.0002
		Height	50.2503 m	.0011	50.1931 m	.0013
4	ET152	Latitude	24° 49′ 13″.565180	.0024	24° 49′ 13″.573133	.0002
		Longitude	56° 08′ 11″.345577	.0024	56° 08′ 11″.353143	.0002
		Height	317.3228 m	.0026	317.1499 m	.0016

Table 5: Established Stations Coordinates

6.2 Coordinate Transformation

Bursa-Wolf 3D Model has been used to derive the transformation parameters between IGS2000 to ITRF93. Two (2) sets of parameters have been derived and the results are as in *Figure 5* and *Figure 6*.

```
Dx = -0.79046 +- 1.52816 m
Dy = 5.14964 +- 0.78552 m
Dz = -7.95080 +- 2.20140 m
Rx = -0.28399 +- 0.06204 "
Ry = 0.07519 +- 0.05969 "
Rz = 0.08915 +- 0.04278 "


Stand. Error of unit Weight So = 0.013


Point vx vy vz

0BP5 0.0046 0.0165 0.0132
E228 -0.0123 -0.0127 -0.0088
E145 0.0103 0.0028 -0.0023
E152 -0.0026 -0.0066 -0.0021


Point N E U

0BP5 0.005 0.006 0.020
E228 -0.001 0.003 -0.020
E145 -0.005 -0.007 0.006
E152 0.001 -0.002 -0.007
```

Figure 5: Six (6) Parameters Transformation

```
Dx = -0.68703 +- 1.76248 m
Dy = 5.30057 +- 1.19260 m
Dz = -7.86582 +- 2.44841 m
Rx = -0.28399 +- 0.06774 "
Ry = 0.07519 +- 0.06518 "
Rz = 0.08915 +- 0.04671 "
S = -0.03165 +- 0.17377 ppm


Stand. Error of unit Weight So = 0.014

Point vx vy vz

0BP5 0.0049 0.0166 0.0127
E228 -0.0128 -0.0120 -0.0094
E145 0.0093 0.0033 -0.0019
E152 -0.0013 -0.0079 -0.0013


Point N E U

0BP5 0.005 0.005 0.020
E228 -0.001 0.004 -0.020
E145 -0.005 -0.006 0.006
E152 0.002 -0.003 -0.007
```

Figure 6: Seven (7) Parameters Transformation

From *Figure 6* it shows that the magnitude of scale correction is relatively small and will not give any significant difference in coordinates over small area if either six (6) or seven (7) transformation parameters being adopted.

7. CONCLUSION

It can be concluded that the adjusted coordinates of DVRS stations are of high quality. With seven IGS stations avilable surrounding Dubai, sufficient data and the capability of the processing software the DVRS stations coordinates were defined on ITRF2000 reference frame within 1.5cm accuracy.

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