INCREASING THE ACCURACY, EFFICIENCY AND COVERAGE OF DVRS BY ADDING THREE MORE REFERENCE STATIONS TO THE EXISTING NETWORK.

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Key words: Virtual reference Station, GNSS, Base Station, Rover Receiver, WGS-84,

SUMMARY

The Geodesy and Hydrographic Survey Section of Survey Department, Dubai Municipality had implemented the project "Dubai Virtual reference Stations" (DVRS) for Precise Positioning Services in the year 2003. The Section has reinforced its objectives in technology development and positioning services through DVRS project. The DVRS consists of five continuously operating Base Stations which are uniformly located in different sectors of the Dubai Emirate. The Control Room of DVRS, with a central server, is situated in the Survey Department of Dubai Municipality. All eight stations are continuously receiving GNSS data and are linked to the Central Server by dedicated telephone lines for continuous data communication from Base Station to the central server and vice versa. The GNSS based continuous operating Base Stations in the network send raw GNSS data to the Central Server and the data is processed by a software system called GNSMART. The software performs all quality checks, computes ionospheric & tropospheric errors, satellite orbit errors, and delivers the corrections to the end-users. Employing a GNSS 'Rover' unit, users can directly start survey works anywhere within the Dubai Emirate. When the GNSS receiver is operated, it calculates its position to within a few meters and transfers this information to the Control Reference Station using GSM Mobile Technology in NMEA format. The Control Central Server sends back valid correctional data to the user in RTCM format. This defines the user's actual position to centimeter accuracy.

Since the implementation of DVRS project the Survey Department of Dubai Municipality has been facing problems related network coverage over the entire area of Emirate and some discrepancies in the positioning values derived using DVRS. At present, the Dubai Municipality is having a network of eight DVRS stations including the newly added three more reference stations in the year 2011. In order to establish three more reference stations, suitable sites have to be selected and continuous observation for seven days from all the stations at one second interval to be done. This paper explains the methodology adopted and the procedure we have followed in the inclusion of three more DVRS reference stations to the existing DVRS Network.

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1.INTRODUCTION

The Geodesy and Hydrographic Survey Section of the Surveying Department, Dubai Municipality has developed and implemented a network of virtual reference stations in the year 2003, known as "Dubai Virtual Reference System" (inshort - DVRS) for providing precise positioning services within Dubai Emirate. Technological advances, both in GPS Survey & digital data, have made it possible to obtain accurate positioning in real time and these changes introduced many new opportunities and exciting challenges to the surveying discipline. The Geodesy and Hydrographic Survey Section has reinforced its objectives in technology through the development of "Dubai Virtual Reference System" and has represented the latest concept in the field of Global Positioning Systems.

DVRS consists of five continuously operating Base and are located in different sectors of the Dubai Emirate. The stations are located at i) Al Qusais (DVRS-1), ii) Jabel Ali (DVRS-2), iii) Al Lusaily (DVRS-3), iv)Al Marqab (DVRS-4) and v) Hatta (DVRS-5). The location of the stations are shown in fig.1. The Control Room, with a central Server, is situated in the Geodesy and Hydrographic Survey Section office within the main Dubai Municipality building in Deira. All the five stations are continuously receiving GPS data and are linked to the Central Server through dedicated telephone lines. These lines continuously carries the data to the control unit (Control Central Server), where data is processed, and corrections transmitted to the end-users, as they require.

2. VIRTUAL REFERNCE STATION

The virtual reference station (VRS) is a concept, that can help to reach centimeter-level, or even better accuracy of positioning and requires use of precise dual-frequency carrier phase observations using a network of reference stations. These observations are usually processed using a differential GNSS (DGNSS) algorithm, such as real time kinematic (RTK).

A differential GNSS setup consists of a single reference station from which the raw data (or corrections) are sent to the rover receiver (the user). The user then forms the carrier phase differences (or corrects their raw data) and performs the data processing using the differential corrections. GNSS network architectures often make use of multiple reference stations. This approach allows a more precise modeling of distance-dependent systematic errors principally caused by ionospheric and tropospheric refractions, and satellite orbit errors. More specifically, a GNSS network decreases the dependence of the error budget on the distance of nearest antenna.

The network of receivers is linked to a computation center, and each station contributes its raw data to create network-wide models of the distance-dependent errors. The computation of errors based on the full network's carrier phase measurements involves, the resolution of carrier phase ambiguities and requires knowledge of the reference station positions. The precise positional value of reference station is usually determined as part of the network setup. At the same time the rover calculates its approximate position and transmits this information to the computation server, for example, via GSM or GPRS using a standard National Marine Electronics Association (NMEA) format. The computation center generates in real time a *virtual* reference station at or near the initial rover position. This is done by geometrically translating the pseudorange and carrier phase data from the closest reference station to the virtual location and then adding the interpolated errors from the network error models.

This generated VRS data is then sent to the user through a wireless connection, using the Networked Transport of RTCM via Internet Protocol (NTRIP). Finally, just as if the VRS data had come from a *physical* reference station, the rover receiver uses standard single-baseline algorithms to determine the coordinates of the user's receiver, in near-real-time kinematic or post-processed modes. The main purpose of a VRS station is to reduce the baseline distance between the rover and the reference station in order to efficiently remove spatially correlated errors using differential processing, and to incorporate error corrections obtained from the reference stations network.

To conduct a survey employing a VRS network, the physical stations themselves must be installed over stable sites, preferably distributed homogeneously over the operational area. If possible, the antennas must be fixed in bedrock to ensure long term stability of the receiver's position. Using the VRS technique, highly improved RTK positioning can be performed inside the network area. The precision of RTK positioning using VRS reaches two centimeters in the horizontal plane and four centimeters in the vertical direction (2σ)

3. HOW DVRS WORKS

All continuous operating DVRS Base Stations in the network sends on-line raw GPS data via permanent connection (Modem lines) to the Control Central Server. Here, the data is processed by a software called GNSMART, (developed by of Geo++, of Germany). GNSMART performs all quality checks, computes ionospheric, tropospheric and satellite orbit errors, and delivers the corrections to the end-users. Employing a GPS 'Rover' unit, the users can directly start survey work anywhere in the Dubai Emirate. When a GPS Rover receiver is operated, it calculates its position to within a few meters and transfers this information to the Control Reference Station via GSM (Mobile) in NMEA format. The Control Central Server sends back valid correctional data to the user in RTCM format. This RTCM correction enable the user to determinine the precise value of user's position.

This complete task is effectively achieved at the 'press of a button' in the field. Such real-time kinematic GPS technology enables work to be carried out within the entire network coverage area, with homogeneous absolute position to centimetre or even millimeter accuracy. A multiple GPS reference station approach is superior to a conventional RTK single baseline approach, as it allows for "network-based" homogeneous positioning solutions with centimeter accuracy. The DVR System has already been subject to stringent testing, which found that the expected accuracy to be in the order of 2-3 cm in planimetry, and 3-5 cm in altimetry.

The DVRS reference station network baseline lengths range from 23.4 km to 90.8km. The DVRS station send their GPS measurements on line to the control room server. Three PCs organise, process and archive the data. The communication with the rover is carried out in the duplex mode, where the rover sends its approximate position, calculated ina single positioning mode, to the control station via GSM mobile call in NMEA format. The software calculates the correction at the user location and send it in RTCm format, which are used to correct its data to reach the cm-level positioning.

4. OBJECTIVE OF DVRS

The following are the objectives of DVRS system

• Surveyor will be needing only one rover set of GPS receiver
• Saving of time for setting up base station each time survey work is carried out through classical technique (productivity improvement)
• Minimization of Errors by using special Software.
• No more conventional levelling will be required.
• The whole survey works will be homogenous and matching with each other.
• Least requirement for ground control points.
• Accuracy is guaranteed for the whole covered area compared to classical RTK.
• Multiple users at same time.
• Reduction in Manpower.
• Being economical when you compare to classical surveying instruments

5. DVRS COVERAGE

Since the implementation of DVRS project the Survey Department of DM has been facing problems related network coverage over the entire area of Emirate and some discrepancies in the positioning values derived using DVRS. The DM was having a network of 5 DVRS stations since its implementation in the year 2003.

To overcome the the probelms related to network covergae of DVRS within Dubai Emirate, the Geodesy and Hydrographic Survey Section of Dubai Municipality have added 3 more new reference stations in the year 2011, making the total number of reference station to eight.

The newly added reference stations are i)Jabel Ali New (DVRS-6), ii) Sehal Salam (DVRS-8), and iii) Nazwa(DVRS-7)

To establish three more reference stations, suitable sites have to be selected and continuous observation for at least days from all the stations at one second interval to be done. The absolute ITRF(International Terrestrail Frame)/WGS84 coordinates in Dubai were established by Institut Fur Geodasie in the year 1995 and the project was named as DUREF-95. Continuous GPS observations were made at six selected ITRF stations at that time for establishing DUREF-95 and absolute ITRF/WGS84 coordinates of the 6 stations were precisely computed after seven days continuous GPS observations. The DVRS stations were established with reference to the ITRF framework (DUREF-95) .

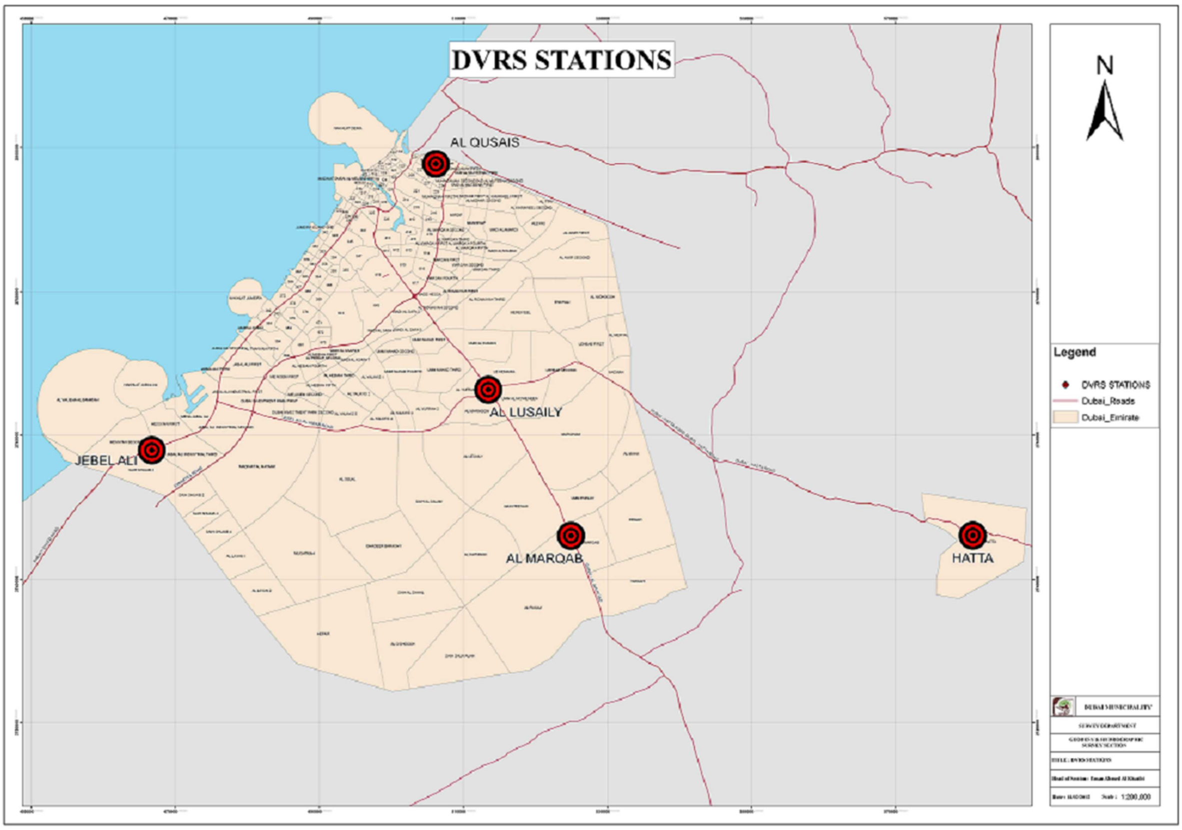

Fig. 1. Location of DVRS stations (Initial configuration)

Out of this six ITRF stations, four are on Dubai Mainland, one station is located at Hatta and one station at Fujairah. Out of the four ITRF stations in Dubai mainland, one station was destroyed during the new developments took place in the coastal area of Dubai. Hence at present only three stations are existing in Dubai main land. As hatta is far from Dubai main land, only the three ITRF stations, which are spread over Dubai main land are taken for continuous observation. These name of the three stations are Head Office ET128, Batu Ramag ET 145 and Border Point BP-5 (please see the table below)

No	Station	Parameter	Value	Error
1	BATU RAMAG ET 145	B	24º 56' 29".091655	0.0002m
		L	55º 14' 06".394970	0.0003m
		H	33.9275m	0.0011m
2	CH.BEACH HOTEL ET 225	B	24º 08' 24".442760	0.0002m
		L	55º 11' 22".395276	0.0003m
		H	1.9740m	0.0011m
3	HEAD OFFICE ET228	B	24º 15' 52".526020	0.0002m
		L	55º 18' 43".449964	0.0003m
		H	2.7387m	0.0011m
4	BORDER POINT BP5	B	24º 12' 36".474185	0.0002m
		L	55º 37' 45".625708	0.0003m
		H	50.2503m	0.0011m
5	HATTA ET 152	B	24º 49' 24".565180	0.0024m
		L	55º 08' 11".345577	0.0024m
		H	317.3228m	0.0026m
6	FUJERA FUGM3	B	25º 06' 57".000851	0.0062m
		L	56º 20' 07".417905	0.0104m
		H	25.6458	0.0075m

Table-1 ITRF (International Terrestrial Frame) station used for defining DUREF95

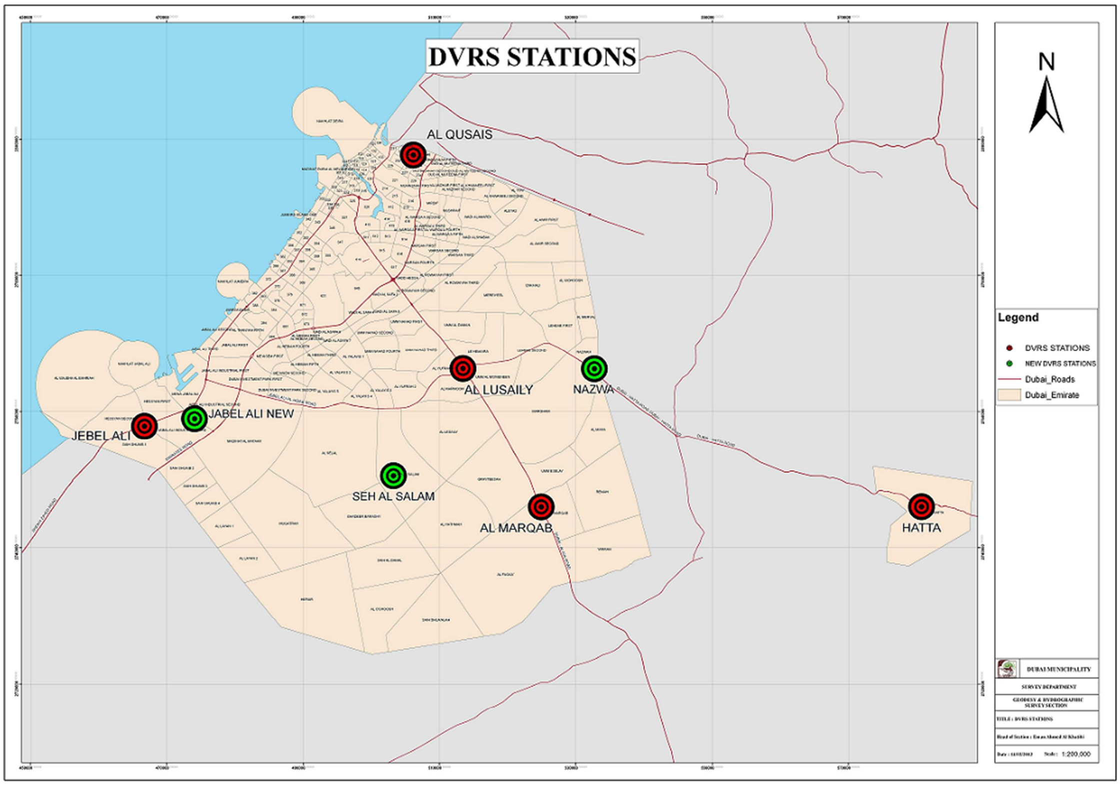

Fig-2 Location of newly added DVRS reference stations (highlighted in green colour)

6. THE VERTICAL COMPONENT OF DVRS

The vertical component derived by GPS refers to the WGS84 datum. A precise gravimetric geoid model was computed for the whole Dubai Emirate to integrate with GPS data to get instantaneous Real Time Three Dimensional Positions.

The Dubai Geoid Model was developed by integrating a comprehensive set of gravity measurements with GPS, leveling and digital elevation data. The computed geoid is a wrapped surface that fits GPS/leveling at the 3-4 cm level RMS. Height or elevation represents the length of the plumbline segment between two equipotential surfaces of the earth's gravity field. Equipotential or level surfaces are surfaces of constant potential in the earth's gravity field. Work is required to move it from one point on an equipotential surface to another point on the next surface.

Due to the earth's flattening and rotation and the fact that its crust contains masses of different density and distribution, these equipotential surfaces are not parallel. In fact they converge toward the earth poles, thus the plumbline or the vertical is not a straight line but curved.

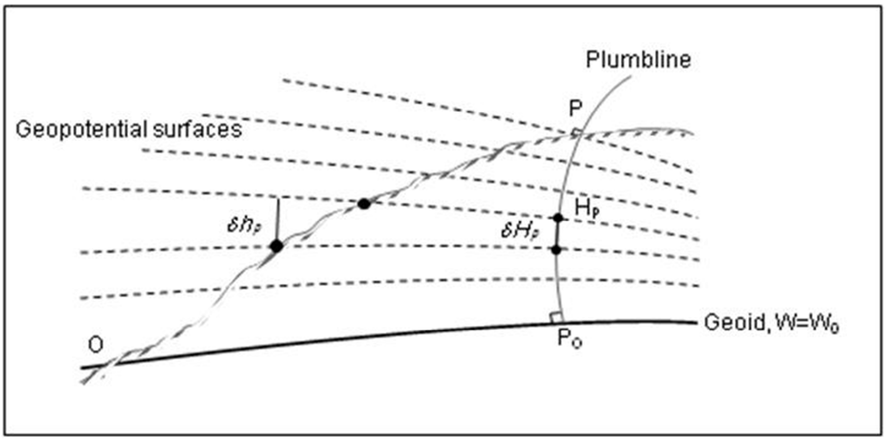

Fig.3. showing various aspects in Geoid Modelling

Work or potential difference is expressed as the product of vertical displacement δh and gravitational acceleration g, such that:

$$W_P - W_O = -\int_O^P g \ \delta h$$

The geopotential number C_P is expressed as geopotential units of a point P and it defines which equipotential surface passes through it. One geopotential unit (gpu) is equivalent to one kilogalmetre which has a value of 10 m^2/s^2. Unlike observed height differences, geopotential numbers are independent on the levelling path taken. They are functions of positions only and misclosures are therefore eliminated. Gravity measurements when combined with levelling yield potential differences or geopotential numbers.

The Dubai Geoid model was developed integrating a comprehensive set of gravity measurements with GPS, leveling and digital elevation data. Gravity data used in determination of the Dubai precise geoid consisted of gravity measurements collected at a network of 1 Km x 1 Km covering the whole Dubai Emirate, referenced to three absolute gravity stations. Other available gravity data were also included from marine gravity surveys in the Arabian “Persian” Gulf (provided by BGI, Toulouse) and KMS-01 gravity anomalies derived from satellite altimetry. The heights of the gravity points were measured with fast static GPS. All gravity data were checked for outliers, and the marine gravity data were compared to the satellite altimetry to check for possible datum errors. As part of the gravity processing, gravity values and ellipsoidal heights of the gravity points were converted into conventional free-air and Bouguer gravity anomalies, using the EGM96 geoid model. The Bouguer anomalies were smooth in mainland Dubai, but a very large gradient went through Hatta. One should however note that with the new geoid model the gravity anomalies could change a fraction of a milligal, but with the GPS leveling fit applied, this will have no practical consequence for the geoid (Forsberg et al., 2001).

The Geodesy and Hydrographic Section of the Survey Department of Dubai Municipality had defined an offshore geoid model and land geoid model for Dubai Emirate in the year 2005 in view of updating the vertical datum of Dubai. A set of approx. 3750 leveled benchmarks with GPS ellipsoidal heights were made available by Dubai Municipality. The GPS data were tied into the ITRF base network of Dubai, and the leveling referred to a fundamental tide gauge at Port Rashid, Dubai. Most of leveling is third order, with some points leveled by trigonometric methods. Many GPS points were repeated RTK measurements (with a 5 cm acceptance limit); while other points in build-up areas were actually determined using classical techniques from nearby GPS points. At points with GPS and leveling a GPS geoid value was derived by

$$N^{GPS} = h^{GPS} - H^{levelling}$$

It should be pointed out that these geoid heights, opposed to the geoid heights determined from global models and gravity data, refer to as local vertical datum, due to the sea-surface topography at the reference tide gauge. In connection with the gravity observations, a leveling line was observed around the perimeter of the Dubai main area, and GPS observations (for gravity station heights) were done in connection with this. The eastern and southern part of the perimeter leveling line GPS was done using rapid static techniques. However, baselines were relatively short, and it appears that the accuracy was good enough also for geoid use (3-5 cm for most points). The perimeter GPS geoid data have therefore also been used for constraining the final geoid. Fig.6 shows Dubai Municipality GPS leveling geoid data, and the GPS geoid data from the gravity survey

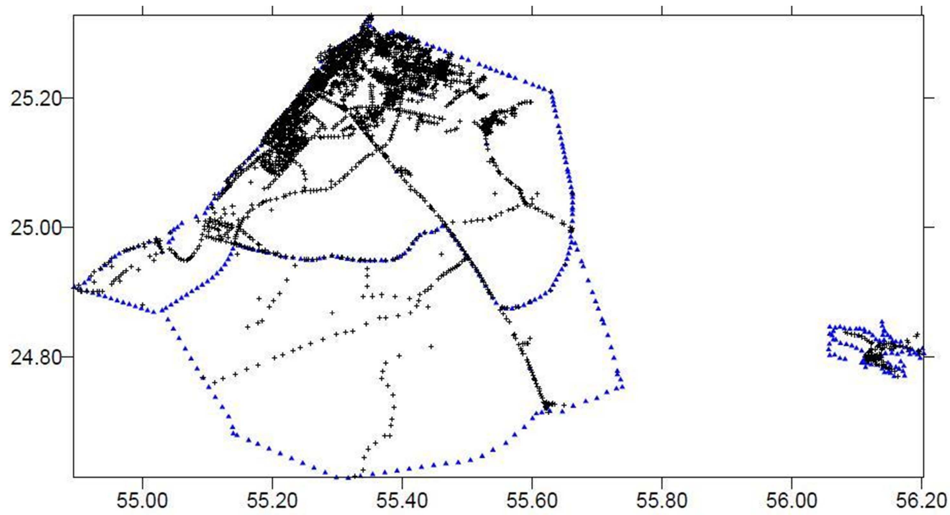

Fig. 4. Available GPS-leveling geoid data shown in black and gravity data is shown in blue triangles.

7. THE DVRS PROCESSING TECHNIQUE

The observation equation for the satellite-to-receiver range computed from carrier phase measurements between the satellite(s) and the receiver(i) can be given as:

$$\emptyset_i^s = \left|\vec{R}_i^s\right| + \lambda\, N_i^s + \delta B_i^s + \varepsilon_i^s \qquad \text{------------ (1)}$$

Where $\left|\vec{R}_i^s\right|$ is the geometric range, λ is the wave length, N_i^s and ε_i^s denote the ambiguity and a total value of the random measurement errors, respectively. The term of biases (δB_i^s)includes the clock related errors (δC_i^s), the spatial correlated errors (δD_i^s), and the station dependent errors (δST_i^s) (e.g. multipath, imaging, antenna phase variation, noise, etc.,) such that:

$$\delta B_i^s = \delta\, C_i^s + \delta D_i^s + \delta ST_i^s \qquad \text{------------(2)}$$

Good estimation of the spatially correlated errors is the key to precise real-time positioning. These errors include orbital, tropospheric and ionospheric errors (δO^s, δT_i^s, and δI_i^s respectively), where

$$\delta D_i^s = \frac{\vec{R}_i^s}{\left|\vec{R}_i^s\right|}\, \delta\vec{O}^s + \delta T_i^s + \delta I_i^s \qquad \text{------------(3)}$$

In the network RTK positioning, many techniques can be employed. Amoung which are: the virtual reference station method (VRS), the area correction parameter technique (FKP), the correction grid method, and the correction function method, (see equations 3,4,and 5). These methods have differences in the amount of data to be send to the user, the processing strategy, amount of computations at the center station, and the type of communications between the network center and the rover receiver. The main software used in processing of the DVRS is the GNSMART [5, and 6], which uses the FKP method to analyze the data to estimate and represent the state of individual GPS errors in real time. All stations of the network are processed simultaneously using un-differenced observables. Therefore, all error components including the clock errors are estimated. A virtual reference station approach is also being employed, where the rover transmits its approximate coordinates to the network, which interpolates the state information computed from the FKP to a VRS position near the user. The correction for a user is composed of a range of correction and a network correction. The former is sent with high update rate (e.g. 1HZ), while the latter change more slowly. The FKP prediction of the distance dependant error term at the VRS position (i) from the reference station (j) takes the functional relationship [6]:

$$\Delta\delta D_{ij}^{s} = \quad f(FKP_i^s, \Delta\Phi_{ij}, \Delta\Lambda_{ij}, \Delta h_{ij}) \qquad \text{----------(4)}$$

Where Δ is the single difference operator, (Φ, Λ, h) denote the latitude, longitude and height, respectively. The errors state has to be transferred to the observation space, because most rover systems are currently not capable to handle state space information due to the standardization difficulty. The VRS correctional data thus yields [5]:

$$VRS_{ij}^{s} = \quad CR_{ij}^{s} \quad + \quad f(FKP_i^s, \Delta\Phi_{ij}, \Delta\Lambda_{ij}, \Delta h_{ij}) + \Delta T_{ij} \quad \text{----------(5)}$$

Where CR_{ij}^{s} is the correlated phase observation referred to the reference station computed from the network solution, and ΔT_{ij}represents the difference in troposphere modeling between processing of the network at the reference station and processing for the virtual reference station. The FKP does not contain absolute tropospheric information but gradients of the troposphere. A linear FKP model is used, centered to a real reference station, and the FKP describes the horizontal gradients for the geometric and ionospheric components in the observation space.

The prediction or interpolation model for state parameters are based on the knowledge about the physical behavior of the respective parameters. The parameter estimation modules are using dynamic models in a recursive Kalman filter algorithm. The state vector used ($\vec{X}$) in brief can be given as

$$\vec{X} \;\; = (X_i, N_i^s, \delta t_i, \delta t^s, \delta\, \vec{O}^s, \delta T_i^s, \delta I_i^s, \delta M_i^s)^T \;\; \text{----------(6)}$$

Where X_i is the vector of unknown, δt_i and δt^s denote the receiver and clock errors and δM_i^s is the multipath error. Some details on the functional and stochastical properties of similar state parameters modeling are given in [5].

8. OBSERVATION FOR THE INCLUSION OF THREE MORE DVRS STATIONS

The Survey Department of Dubai Municipality had started round the clock observation (at one second interval) from November 29th to 7th December 2011 (nine days) from all the eight DVRS stations along with the three slected ITRF station for updating DVRS Network. The whole data was processed to compute the final coordinate of all eight DVRS reference stations (see table-1)

Station	Location	Antenna Height	Antenna Type	Receiver Type
DVRS1	Al Qusais	1.516m	LEIAT504	LEICA GX1230
DVRS2	Jabel Ali (old)	0.516m	LEIAT504 SCIS	LEICA MC500
DVRS3	Al Lusaili	0.516m	LEIAT504	LEICA GX1230
DVRS4	Al Marqab	0.516m	LEIAT504	LEICA GX1230
DVRS5	Hatta	1.516m	LEIAT504	LEICA GX1230
DVRS6	Jable Ali (new)	0.516m	LEIAT504	LEICA GX1230

DVRS7	Sehal Salam	0.516m	LEIAT504	LEICA GX1230
DVRS8	Nazwa	0.080m	LEIAT504	LEICA GX1230
ET 228 (ITRF)		1.496m	LEIAT504	LEICA GX1230
BP5 (ITRF)		0.123m	LEIAT504	LEICA GX1230
ET145 (ITRF)		0.124m	LEIAT504	LEICA GX1230

Table-1 Station data

The following antenna calibration was used, with the constant part of the pahse center postion. (Also there is a variable part, used for the claculation)

Antenna type	Constant part of the phase center position (East, North, Up)
LEIAT504 SCIS	L1 -0.0002 -0.0004 0.0856 L2 -0.0002 0.0001 0.1154
LEIAT504	L1 0.0001 -0.0003 0.0912 L2 -0.0001 0.0001 0.1173

Table-2 Antenna Calibration

The RINEX observation fiels corresponds to nine days GPS observation from November 29 to December 7th is taken for processing. The original data set cionsisted of weekly and hourly files. After formatting, the files genereaaly consited of a full 24-hour, 30-second sampling rate, C1/L1/P2/L2 measurement data set with some non-singificant data gaps. RINEX navigation fiels are unnecessary since IGS final precise orbits are used for processing the data.

All observation, orbit earth rotation parameter data were retrieved from the IGS Global Data Centre at IGN. For any missing expected file, a check for presence was made from CDDIS GDC (NASA), but GDC are really well mirrored so as no other data could be recovered.

The computation process consisted of twofolds. First step is to provide daily quasi free network solutions and the second step is to combine these silution in order to get final corodinates in the properly defined reference frame.

A licenced Bernese GPS software v5.0 is used for processing the data. The Bernese GPS software Version 5.0 is a high performance, high accuracy and higly flexible reference GPS/GLONASS post prcocessing software.

The daily processing steps followed are as below:-

Importing data:

-Import the data (RINEX – Bernese)
-Import orbits (Precise – Bernese standard)
-Import Earth rotation parameters (IGS erp – Berrnese format)

Preprocessing steps:

-Computation of receivers' clocks

-Network definition (single difference file creation)
-Check of phase data (cycle slip detection and repair)

Processing steps through ionosphere – free double difference processing

-Pass1: approximate coordinates and tropospheric delays (network)
-Pass 2: ambiguity resolution via quasi ionosphere-free QIF process (baselines)
-Pass 3: free coordinates / troposphere delays estimates (network)
-Save normal equations for further combination

Interpretation of the results

-Ambiguity fixing results
-Variance factor range
-Helmert adaption from IGS stations computed coordinates to actual ones.

After obtaining daily solutions, related normal equations are merged in a least square process in order to provide final reference free combined solution. This solution is Helmert-aligned to IGS05 at mid-epoch of observtions. Residuals are ckecked to access consitency of this solution. The reult acheived is a best fitting solution to IGS05 reference frame considering the station avialble at the mi-epoch of observations.

9. FINAL COORDINATES

The solution os transferred at epoch 2005.0, which is the epoch of IGS cumulative solutions. Station velocities are unavilable, so a rotation model for the Arabic Plate is used.

Rotaion about X ais = 0.369 º /My
Rotation about Y axis = 0.032 º /My
Rotation of about Z axis = 0.440 º /My

The position and velocities of the station at epoch 2005.0 are derived by application of this roation

10. RESULT

After the introcution of three more station to the existing DVRS system, the coverage of DVRS over the entire Dubai Emirate become sucessful. The results appeared to be of high precision and reliability. A relative accuracy of 10mm horizontally and 15mm vertically is acheived, although depending on the actual monument stability

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BIOGRAPHICAL NOTES

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