ESTABLISHMENT AND EVALUATION ASPECTS OF CYPRUS GPS PERMANENT NETWORK FOR MAPPING APPLICATIONS

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ABSTRACT:

The study describes the design, installation, testing and use of a pilot permanent GPS stations network in Cyprus, for mapping purposes. In addition, it evaluates its operation in order to produce the infrastructure mainly for mobile mapping applications but also any other type of relevant applications. The Continuously Reference Station Network is designed and established according to various quality criteria, which are discussed. Several applications using all the available information in static, kinematic in post process and RTK using virtual reference station technique and autonomous navigation mode are carried out. Three main groups of applications for mobile mapping are identified and investigated: the first group concerns applications requiring low accuracies (up to 10m), the second group concerns applications requiring medium accuracies (up to 1m), and the final group concerns applications requiring high accuracies (up to few cm). A detail report about the experimental results, aspects and conclusions is presented. Emphasis is also put on a digital aerial acquisition project, using GPS/INS measurements. Furthermore, in order to test the effectiveness of using C/A code-data for low cost DGPS applications in real time, appropriate software using the VRS technique is developed. For that reason measurements of three permanent GPS stations are analyzed for a determination of a kinematic chain which took place in the broader area of Pafos, Cyprus. The positional accuracy of the path is finally assessed by comparing the results with post processed trajectory. The results showed that using the VRS station concept with our developed software named “3VRS”, similar accuracies can be achieved in distances of up to 20km from the nearest reference station as for short baselines in the single station concept.

1. INTRODUCTION

The paper presents the results of a research project which targets on the design, establishment and evaluation of the operation of a GPS permanent network in Cyprus which was named Positioning System Improvement (PSI).

According to the design specifications, the PSI network consists of nine dual frequency GPS receivers which are established at the territory of the island which is under the control of the Republic of Cyprus and illustrated in Figure 1. The purpose of the establishment of each station is to provide single and dual frequency data for relative positioning and also to transmit DGPS and RTK data for real time users (Weber G., 2001).

The PSI network may have a wide regional coverage where ever cellular phone service is available. As a result the GPS measurements could be used in airborne mapping operations such as aerial photography, LIDAR, remote sensing, bathymetric, boundary and cadastre surveys, topographic surveys, emergency and accident response systems, construction surveys, tracking asset inventory, utility location and recovery, mobile mapping-imaging, pavement inventory, precise timing, as well as, deformation studies, atmospheric modelling and seismic monitoring. Several case studies using phase and code GPS data, especially on kinematic mode, are carried out and the evaluation of the results is discussed.

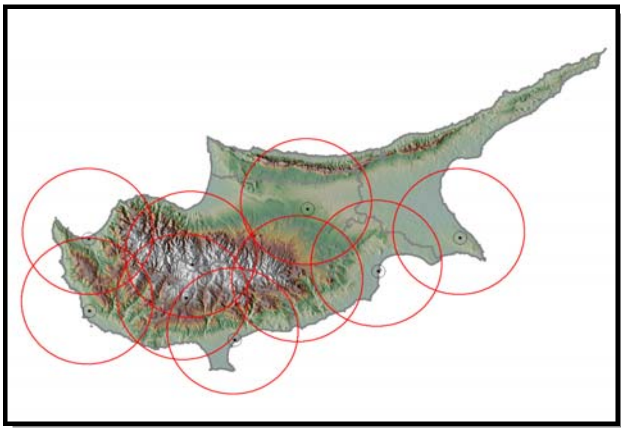

Figure 1. The designed Cyprus permanent GPS network

2. NETWORK DESIGN AND INSTALLATION

Firstly, the optimum operation of the GPS reference station network has to be ensured. For this reason, the key factors which are taken into account in selecting a site for our permanent stations are introduced below (Leica, 2001).

- GPS Sky Visibility
- Electromagnetic interferences

- GPS Antenna Stability
- Multi-path
- Easy access
- Network Geometry
- Electrical Power and Communications for **R**eal **T**ime **K**inematic (RTK) Surveys
- Equipment Protection

According to the island topography, the distance between stations of the network must be under 35 Km, while the height could vary from 100 m up to 1900 m.
In addition to the aforementioned key factors, other important details like:

- Monument construction
- Antenna installation
- Water proofing

should be taken into account.

Special attention should be given to the radio noise sources and in general the interference which can be assumed as originated from these sources. As it is known, the strength of the GPS satellite signal is very low, so nearby sources of electrical or radio noise can cause significant problems by interfering with the GPS signals. These types of noise may originate from:

- Electrical transmission lines
- Nearby commercial radio or television broadcast stations
- Radio dispatch stations
- Police, fire & other emergency services
- Taxi services
- Pick up and delivery services.
- Airports

All these parameters and restrictions have been taken into account while designing the PSI network and quality of signal tests were performed (Leica 2006). The designed network geometry is depicted in Fig.1

3. NETWORK ASSESSMENT

3.1 The Challenge of VRS

Recent developments in differential GPS services are focusing mainly on the reduction of the number of permanent reference stations, required to cover a certain area, and on the extension of baseline lengths between reference and rover receivers. The most advanced technique nowadays is the Virtual Reference Station networks. The name of this method results from the fact that artificial observations for a (non existing) ‘virtual’ GPS station are created, using the real observations of a multiple reference station network.

The concept idea is that a user is activated inside a network of permanent reference stations, that are connected with a central control station. User receiver transmits its navigated position to the central station. The communication is usually performed with cellular phones (GSM) and in future with Universal Mobile Telecommunication Service (Hada et.al, 1999,2000). The contribution of the network is the knowledge of the errors behaviour, specifically of those that are distance dependent. So, ionospheric and tropospheric refraction and orbit errors are modelled and can be interpolated at any position inside the network. The artificial observations for the user approximate location are created and then transferred (through RTCM format) back to the user (rover station). On the rover side, standard RTK or DGPS algorithms are used to obtain the correct position. The result is the increment of baseline lengths and the reduction of initialization times (Rizos, 2002, Fotiou and Pikridas 2006).

During these projects, the PSI network was established and the VRS method was tested with C/A code data using custom-developed software. The results showed always a positional accuracy of better than 1 m.

3.2 Description of Applications

In the next paragraphs, a number of test cases, based on the PSI network, are presented. These span a wide spectrum of different geomatics problems, while the main focus remains the proof of the productivity of the network and the evaluation of its operation.

For this purpose, different techniques, hardware and software components have been used. The applications cover also a wide range of accuracy requirements (from several cm to several m) and all of them have been performed in Cyprus.

3.2.1 Case 1: Application of VRS Technique

In order to test the accuracy achievements of the virtual reference station concept, a test network, consisting of three dual frequency GPS receivers, was temporary established in the broader area of Pafos. The network was first measured and adjusted in order to determine accurate coordinates. Inside the area (triangle) of the three permanent stations a low cost (less than 3.000 €) rover receiver was also activated to perform a kinematic chain of about 2 hour’s duration. The survey took place almost 20 Km away from the closest station. A user friendly VRS software called “3VRS” was developed and artificial C/A code observations were created for the first navigated position of the rover receiver using the data of the closest station. Investigating the effectiveness of the VRS technique three different solutions were derived.

- Phase solution with fix ambiguities
- DGPS solution with post-processing
- DGPS solution using VRS data

The results from the comparisons between the various solutions show a precision for the X and Y components better then 0.5 m and about 1.5 times worse for the Z component (Table 1). Therefore our tests prove that an accuracy increment for this kind of baseline lengths can be obtained when the VRS method is applied.

Difference of components	Maximum value (m)	Minimum value (m)	Mean value (m)
ΔX	0.62	0.14	0.26
ΔY	0.74	0.16	0.32
ΔZ	0.84	0.01	0.65
ΔS (position)	1.28	0.21	0.75

Table 1. Characteristic values of the differences of the component and position between the VRS (DGPS) solution (C/A code and L1 frequency processed only) and the one derived from the phase measurements

3.2.2 Case 2: Real-Time Kinematic Positioning Highway Mapping

Various RTK survey tests were executed at different distances from the permanent stations aiming at testing the substructure and the accuracy quality of the network. The equipment used was the Leica Geosystems SR520 and GRX1230 receivers. The initialization test (KIS) was performed using the GRX1230 geodetic GPS receiver in the broader area of the Paralimni town. The campaign was scheduled in order to have the maximum GPS visibility. The recording interval for the kinematic chain was set equal to 2 sec. The measured points were processed from the two permanent stations of Larnaca and CavoGreko (southeastern of Cyprus) in order to test the method effectiveness on various baseline distances. Specifically, the test distances varied from about 1 to 21 Km.

For every occupied point, we calculated the distance between the point obtained from DGPS and the one from kinematic post-processing (KIS-PP) (Pala et.al., 2003, Xinhua, WU. et.al., 2004). In addition, some points of the kinematic also were measured with RTK in order to simultaneously evaluate the accuracy of this method against the other techniques. It is critical to report that several problems came up, mainly due to obstacles to the radio-modem signal communication. Therefore, a GPRS connection is preferable (Gao Y., 2002). Also a post processed single point position (SPP) based on C/A code data was estimated and evaluated accordingly. A part of the kinematic chain trajectory starting from the broader area of the Paralimni with direction to Larnaca is shown on the following Figure 2.

Figure 2. The GPS Kinematic trajectory

The comparison between obtained positions from phase (fixed) solutions, using different permanent station data, shows an agreement at the order of few cm, value which meets the manufacture's accuracy specification.

Also, the results confirmed the expected sub-meter precision for the code differential mode. Such accuracy data are quite useful for fleet management. In addition, it is proved that DGPS, due to the high rate of collecting the necessary information, is probably the best mobile method for map generation (or update) for scales 1:5000 and smaller. There is no need for initialization, cycle slip fixing and ambiguity resolution and of course the installation cost is highly reduced.

The following diagram (Figure 3.) shows the height differences between the post-processed kinematic solution and the RTK solution, for selected points of the kinematic trajectory. As it is known the height dimension is the mainly affected one so this quantity was selected to represent the worse case. It is clearly shown that the differences are lower than 5 cm except for a few points where the re-initialization was necessary after loss of signal lock (lower than 4 satellites tracking) (Hofmann-Wellenhof et.al., 1997).

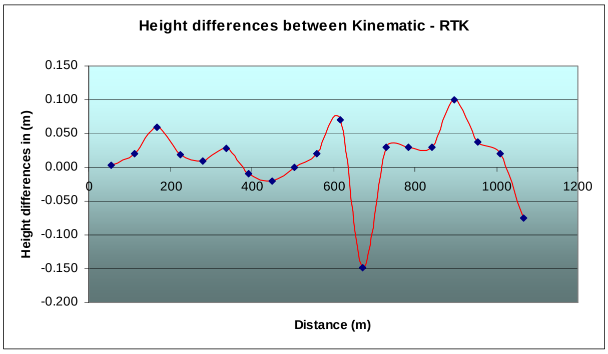

Figure 3. Height differences between Kinematic and RTK solutions

In addition to the above test, another survey was concurrently contacted using only low-cost handheld GPS receivers (at cost of 300 €), aiming at accuracies at the order of 1 m. The achieved DGPS results confirmed that accuracies of better than 1 m are achievable under regular survey conditions (Fig. 4).

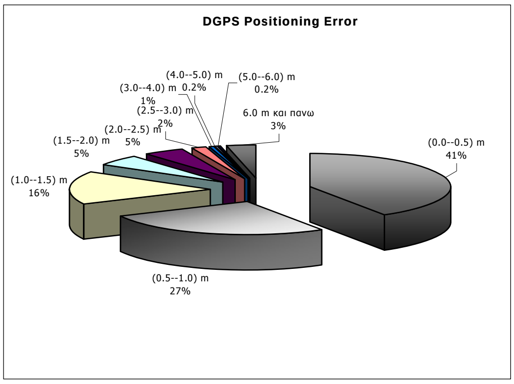

Figure 4. Accuracies of the DGPS solution. In 68% of the cases the accuracy is better that 1 m.

3.2.3 Case 3: Parcel identification and measurement with low-cost GPS receivers

This application aims at the evaluation of the performance of the PSI network in the determination and improvement of the position of parcel boundaries for the update of the national vineyard cadastral. With the use of data from low cost portable GPS receivers as also from the referenced stations of the Cyprus PSI network, the technique of relative kinematic positional determination is applied using C/A code data. The parcels chosen f are shown in Figure 5. The closest permanent PCI network station is used as a referenced receiver.

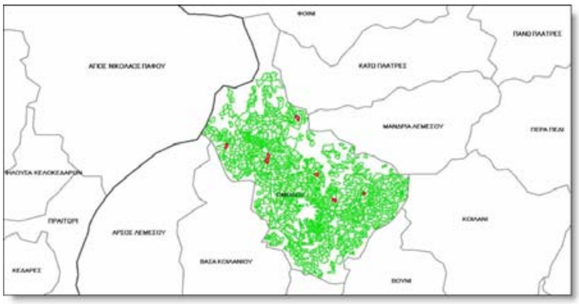

Figure 5. The chosen vine-parcels in the province of Lemesos

After the analysis and the processing of the measurements, with the use of algorithms and appropriate software programs and the help of the RTCM protocol, the final values of the coordinates of the boundary points are derived. Figures 6,7 and 8 show the boundaries of the three chosen parcels as they are defined from the cadastral records (white color) and from the GPS measurements (red color). The improvement of their boundaries positional determination is obvious and can reach a few decades of meters. Figure 9 gives the range of the corrections of the boundaries positions. With the application of the kinematic positional determination, in real time, the accuracies achieved are better than 1 m.

Figure 6. Boundaries of vine-parcel 1

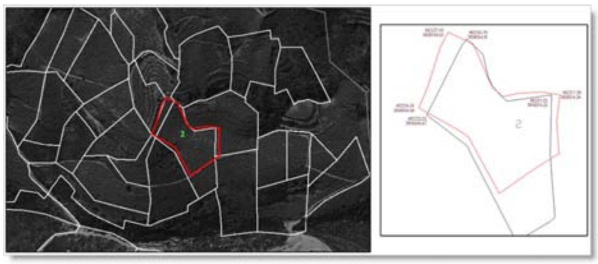

Figure 7. Boundaries of vine-parcel 2

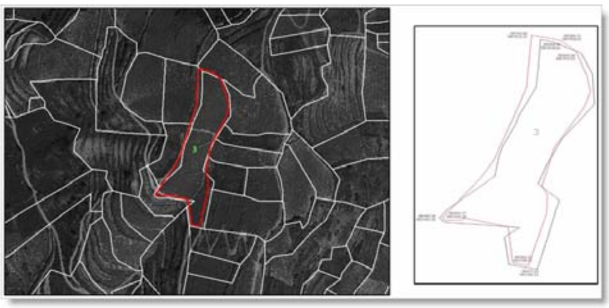

Figure 8. Boundaries of vine-parcel 3

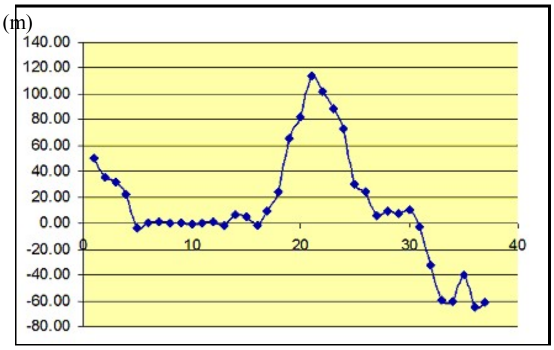

Figure 9. The range of the correction values of the boundaries positions of the parcels

3.2.4 Case 4: Aerial Photography Combined with GPS/INS data

During an aerial photography campaign, the PSI network was used in conjunction to GPS/INS data of the aircraft, the purpose being the determination of the flight line (Fig. 10.). Double frequency GPS receivers aboard the aircraft were used and the technique of relative kinematic positioning determination was applied (on-the-fly solution of phase ambiguities). The GPS stations of the PSI network were used as referenced receivers. The final coordinates of the photo centers as well as the orientation angles were determined. The positional accuracy was evaluated with the use of data from permanent GPS stations. The achieved results of better than 10cm in position and 20^{cc} in angles are acceptable at least as good approximations, and depending on the final map scale, as final results as well.

Figure 10. Determination of flight trajectory for direct geo-referencing of aerial photography

4. CONCLUSIONS-DISCUSSION

This paper introduced a new permanent GPS network installation study and describes basic test cases used for location and mapping services.

The achieved results (Table 2) show that the positioning precision level obtained for differential GPS, phase fix solutions, RTK and single point positioning is actually more optimistic than expected (based on the effectiveness of each method and the used hardware).

Method	Position Error <2 m	Position Error <5 m	Position Error <10 m	Position Error > 10 m
SPP	8 7.3%	22 18.2%	81 73.6%	1 0.9%
DGPS <5 Km	108 98.2%	2 1.8%	--	--
DGPS <10-25 Km	107 97.3%	2 1.8%	1 0.9%	--

Table 2. The estimated location error by single and differential GPS positioning

Several static and RTK tests (via internet) will be applied in the near future in order to evaluate the capability of the network on longer baseline distances using all the proposed permanent stations.

Using the VRS station concept with our developed software "3VRS" similar accuracies can be achieved in distances of up to 20 Km from the nearest reference station as for short baselines in the single station concept. This can be done also with few epochs. Therefore the distances between the reference stations in a permanent GPS network can be enlarged which results in large cost savings for the establishment and maintenance.

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