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Experiences using Real Time Kinematic GPS Positioning for erosion and hydrographic surveys in Doñana National Park (Spain)

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BIOGRAPHY

Josep A. Gili (Ph.D. in Civil Engineering) is Associate Professor at the Technical University of Catalonia (UPC), and Deputy for Education at the Institute of Geomatics (IG). His main field of work is surveying and landslide monitoring using GPS. As the rest of the authors, he belongs to the UPC Department of Geotechnical Engineering and Geosciences, where they form the surveying research group of a Spanish CICYT project (1998-2000), devoted to the study of hydrological and geomorphological processes in the wetlands within the Doñana National Park.

ABSTRACT

Last decade, real time kinematic (RTK) GPS methods have been developed with high productivity and good theoretical precision, enabling the coverage of wide areas. The main objective of this contribution is to ascertain the performance of this method in the study of test area "A" (about 12 km^2) within the Doñana National Park wetlands. One of the aims of the research Project was the detection and monitoring of sub-decimeter level terrain changes due to water erosion or sand sedimentation. The technique used is GPS navigation and profiling along N-S paths 50 m apart, during the dry season. The first survey has been carried out in summer 1998, including repeatability tests. About 20000 terrain points have been obtained. The survey has been repeated in July 2000. After filtering and editing, conclusions about precision have been derived from the repeatability test and comparing both surveys. Other practical remarks are related with the total number of GPS satellites available during the fieldwork, the initialization process using RTK at increasing distances, and the GPS positioning during high geomagnetic activity days.

Keywords: GPS, RTK, sediment, erosion, wetlands, Doñana

INTRODUCTION

The Doñana National Park is a high ecological value area located at the SW of Spain, between Seville and Huelva (figure 1).

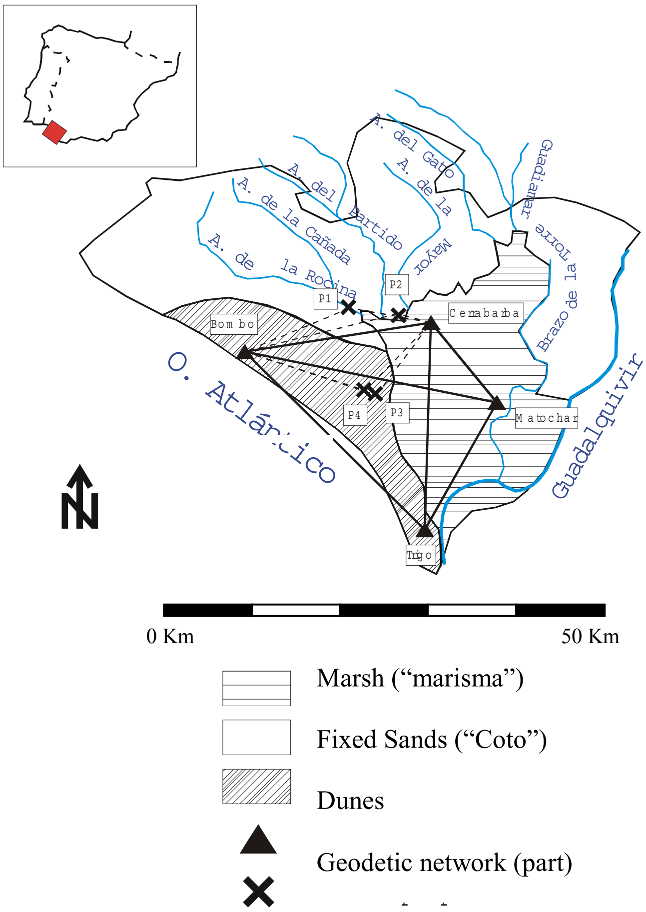


Figure 1: Doñana National Park, general geological map showing the different eco-zones.

It has to be highlighted the big extension of the Park and the surroundings, about 500 Km^2. About half of them are wetlands during the humid season, but will almost disappear in summer. In such a vast area, the positioning and navigation with GPS should be a valuable help for a wide range of works: among others, topographic hydrological, geological or biological surveys.

However, some previous work had to be carried out in order to provide a set of known precise reference points (horizontal and vertical), not existing at that moment.

Within the MADRE sub-project #2 there were 3 research groups: groundwater hydrology, geomorphology and surveying.

The main goals for the surveying group have been:

- To establish the Geodetic Network to support all the measuring works of the rest of the groups (within the project or in the future)
- The Geoid model: special attention has been devoted to the undulation correction (N), necessary to transform ellipsoidal heights to orthometric heights
- Kinematic GPS profiling (RTK method) over two test zones (A & B) within the National Park

In next sections more details will be given about this 3 subjects. Additional information can be found in the references

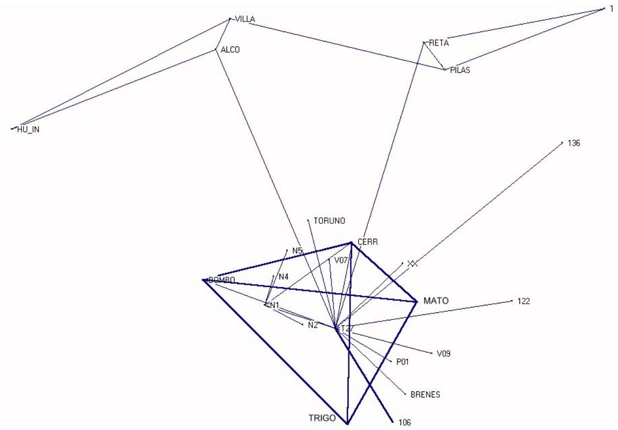


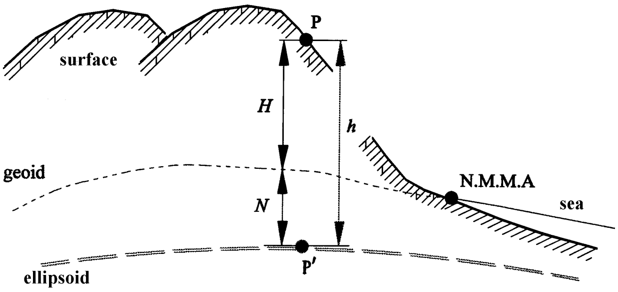
Figure 2. a) Geodetic Network established for the project. b) Example of geodetic point (Retamales), used to link the local network with REGENTE, (IGN)

GEODETIC NETWORK

A network linking all the geodetic points in the region (figure 2) has been established, observed and computed (GPS Fast-Static method, Trimble 4000 SSi receivers)

GEOID MODEL ADJUSTMENT

The geoid is a surface of constant gravity potential that corresponds with the mean sea level (figure 3). Most of human activities need the heights to be refereed to this non-regular surface (orthometric height, H), for example, the hydrological studies. But GPS heights are primarily ellipsoidal ones (h). To transform h to H, we need to map N, the undulation, variable from point to point.



$$\boxed{h = H + N}$$

Figure 3. The geoid undulation (N), the ellipsoidal height (h), and the orthometric height (H).

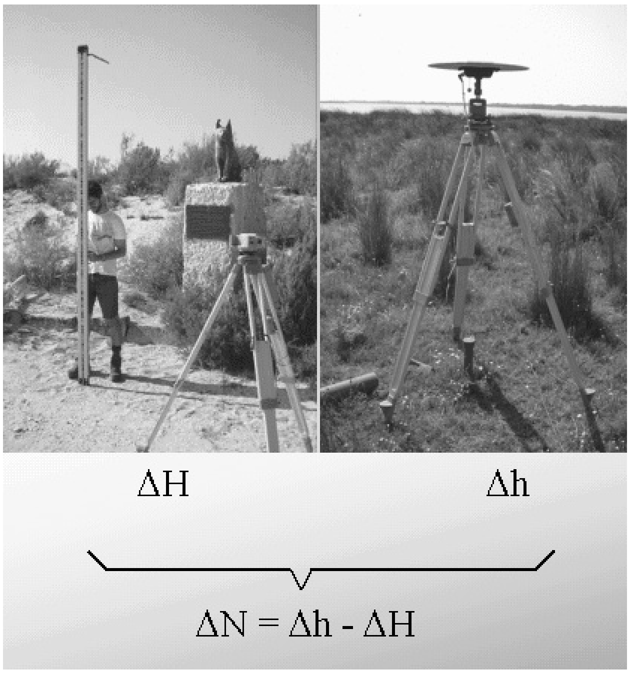


Figure 4. "Double leveling" for a preliminary check of the geoid gradients.

The IBERGEO95 (Sevilla, 1995) is a "local" geoid adjusted for the Iberian Peninsula. But, for a given area, it has not enough resolution. In the other hand, in the Guadalquivir River mouth, the predicted gradients of the geoid are in the order of 5-8 cm/km. This implies that the geoid adjustment is especially critical in Doñana. However, this subject was not identified properly at the time the Project was prepared.

In the first campaign (1998), we made a preliminary check of the geoid gradients by means of "double leveling": measuring ΔH trough geometric leveling (figure 4) and Δh trough GPS leveling of selected baselines, we obtain ΔN and the gradients. The results of this check are shown in the figure 5.

In the second campaign (summer 2000), additional leveling data, along with gravimeter measurements, have been obtained, that are now under computation to obtain an improved geoid, adjusted for Doñana region.

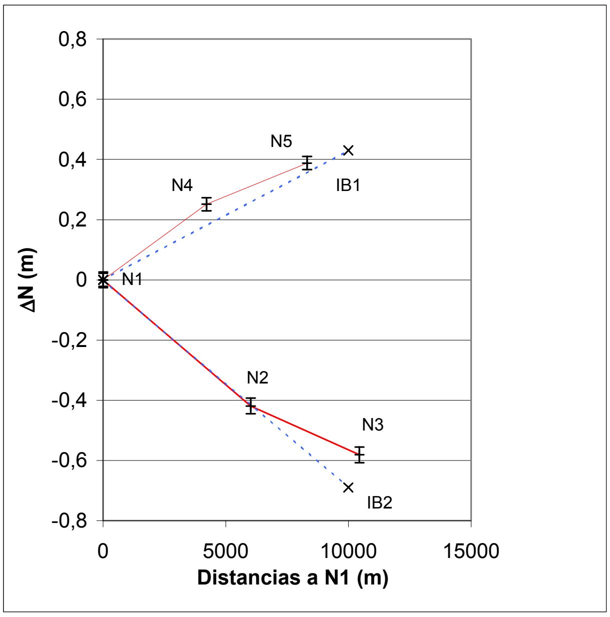


Figure 5. Geoid Gradients measured in two lines (N1-N3 and N1-N5, see figure 2), ranging from 5 to 7 cm/Km. In dashed lines the values from IBERGEO95.

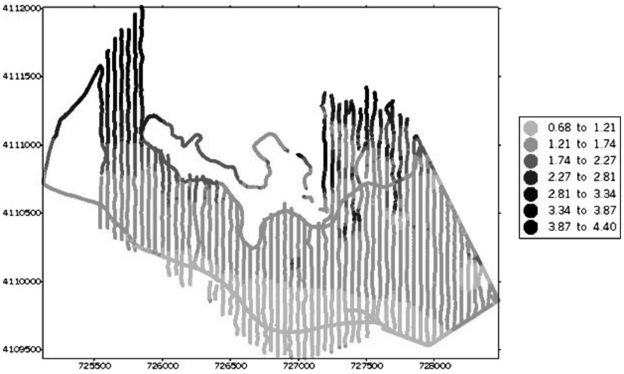


Figure 6. Profiles measured with GPS-RTK (zone A "Matasgordas"), in summer 1998.

PROFILES WITH GPS-RTK

The aim of the survey was the modelling of the topography in two test zones (A & B) within the National Park.

The first survey has been carried out in summer 1998 in the zone A ("Matasgordas"). About 20000 terrain points have been obtained (figure 6). The GPS technique was RTK (Real Time Kinematic). The navigation and profiling were conducted by crossing the "marisma" (marsh) along N-S paths 50 m apart, during the dry season, something like a bathymetric survey but without water. The "base" station (fixed known point) and the "rover" vehicle are shown in figure 7. The navigation and the coordinate adquisition were done with the software Hypack on a portable PC.

In addition to establish the initial topography, the aim of the project was to test the performance of this GPS profiling to detect sub-decimeter level terrain variation. These geomorphological changes can be produced by water erosion or sand sedimentation by flooding, wind or animal/ human activity. For this reason, the survey has been repeated in July 2000. The mean productivity is shown in table 1.

Figure 7. *Top*: receiver and radio link at RTK "base". *Bottom*: "Rover" vehicle, with the GPS and the radio antennas at the roof.

Table 1. Mean productivity in profiling in zone A

	1998	2000
Working days	3	2
Aprox. Total # Ha (50m profile)	275	360
Mean productivity	127 Ha/day	
Max. Productivity	250 Ha/day	

After filtering and editing the raw data, conclusions about precision have been derived from the repeatability test and comparing both surveys.

Figures 8 shows two examples of such double profiles.

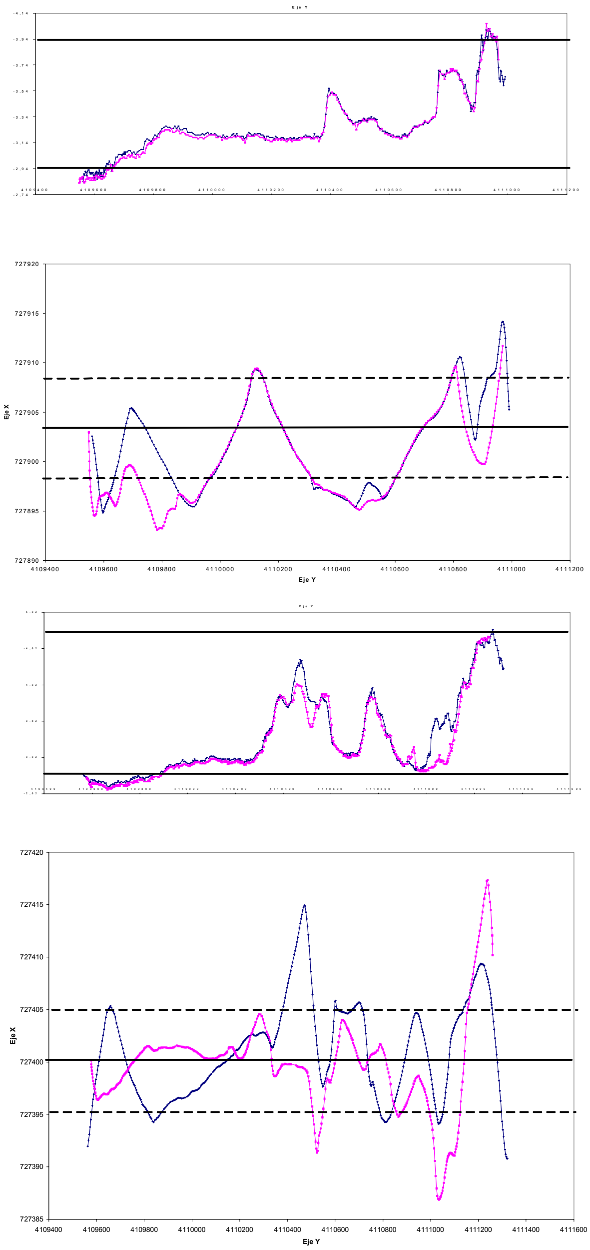


Figure 8. Profile and track of lines 040 (repeatability test, july 2000) (*top*) and 050 (july 2000-july 1998) (bottom). In the profile view, the two horitzontal lines are 1 m apart, and in the plan view, the dashed lines are at 5 m distance from the continuous line (the planned path).

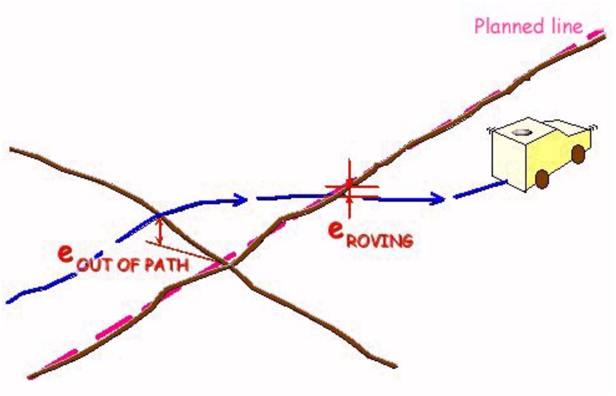


Figure 9. Discrepancies between elevations

The central part of line #040 shows a repeatability test following the same track. Accordingly, the elevation view show low discrepancies. On the other hand, the line #050 includes two tracks from different campaigns. The separation in plan ranges from few meters to up to ten meters.

In figure 9, the structure of the discrepancies ($\mathbf{e}$) between profiles is outlined:

$$\mathbf{e}_{Z,\ TOTAL} = \mathbf{e}_{Z,\ ROVING} + \mathbf{e}_{Z,\ OUT\ OF\ PATH} \qquad (1)$$

The out of path navigation is due to natural obstacles (i.e. trees) or to human mistakes of the navigator. The term $\mathbf{e}_{Z,\ OUT\ OF\ PATH}$ depends on the offset and on the cross slope angle. It could be reduced with a more careful navigation (low speed). However, the productivity will descend as well.

Even in the case of navigation "on the path", there will be an error, $\mathbf{e}_{Z,\ ROVING}$, that includes intrinsic GPS-RTK error, dynamic vehicle effects, the along track interpolation and others.

Assuming independence between both terms and absence of systematic errors, we might establish statistically the following variance relationship:

$$\sigma^{2}_{Z,\ TOTAL} = \sigma^{2}_{Z,\ ROVING} + \sigma^{2}_{Z\ /\ PATH} \qquad (2)$$

But, the existence of certain systematic terms (for instance, the error in antenna height measurement for different profiles) avoids this analysis. Therefore, the error considerations will follow equation (1).

Fortunately, the terrain slope angle is low in this project, according to the extremely smooth topography in Doñana test zone "A": most part of the 12 Km^2 area falls within 1 m level difference. Also, the navigation offset has been less than 5 m most of the time. We have verified that, at least in the marsh, the term $\mathbf{e}_{Z,\ OUT\ OF\ PATH}$ is negligible in front of $\mathbf{e}_{Z,\ ROVING}$.

Table 2:
Discrepancies in Z along 15 selected profiles (Zone "A")

Line #	nº obs.	mean (m.)	RMS (m)
030	39	-0,044	0,046
032	65	-0,038	0,045
034	191	-0,039	0,042
036	217	-0,016	0,022
038	209	-0,031	0,037
039	161	-0,008	0,024
040	376	0,012	0,018
041	272	-0,004	0,016
042	144	-0,008	0,016
045	147	0,017	0,024
047	346	-0,011	0,019
049	174	0,024	0,033
050	328	0,033	0,038
051	176	0,006	0,027
052	338	0,020	0,030
TOTAL	3183	-0,0013	0,0295

This last term may be evaluated in special zones where the out-of-track offset is less than 5m (see table 2). For instance, in repeatability tests conducted running twice the same planned line following exactly the same tracks (central part of line #40, figure 8). Or from the differences in elevation ($Z_{2000} - Z_{1998}$) at each abscisse along all the lines, excluding the zones with geomorphological changes.

The overall RMS for $\mathbf{e}_{Z}$ is about 3 cm. So, we can state that the method used may detect and monitor sub-decimeter level terrain changes due to water erosion or sand sedimentation in the Zone "A" of the project.

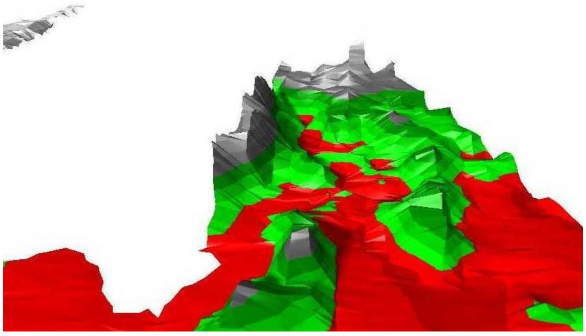


Figure 10. DTM of Zone "A" marsh bottom

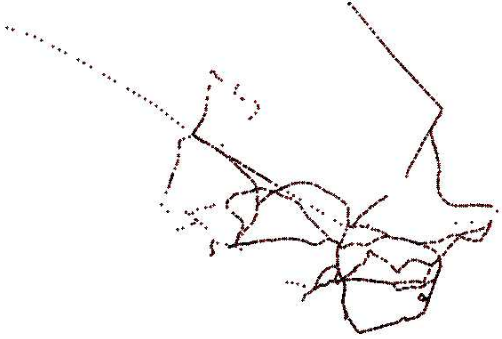


Figure 11. GPS survey of Zone "B" of the project

With the profiles, DTM and perspectives of the Zone "A" can be displayed (figure 10)

The GPS–RTK method has been used also in test zone "B" (lagoons), but following the roads, natural paths and forest tracks of the area (figure 11).

CONCLUDING REMARKS:

During the field campaigns, the total number of satellites available has been sufficient, between 6 and 9 most of time. Zone "A" is completely "open" to the sky. In zone "B" problems arose with the trees and wood.

The RTK method has succeeded always in the initialization phase within the specified time, even at 6 or more Km from the base and with the last year high geomagnetic activity days.

As expected, the discontinuity of Selective Availability has had no noticeable effect between 1998 and 2000 campaigns.

It is not convenient to navigate along the "marisma" at high speeds due to vegetation, animals and unseen obstacles. Even in the smooth topography of Doñana Park, it is difficult to follow the planned lines completely. Offsets up to 10 m might be usual. For these reasons, it is not envisegable to extend the methodology presented in this paper to the rest of the "marisma". To obtain the precise topography of the whole marsh, other methods as Airborne Laser Scanning should be used.

It is worth to remember that the knowledge of the geoid model is of paramount importance to transform the "GPS heights" (WGS84) to orthometric values, especially for hydrographic works. This subject was not identified properly at the time this Project was prepared, and required an extra effort.

ACKNOWLEDGMENTS

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