GPS-GIS INTEGRATED SYSTEM FOR ELECTROMAGNETIC POLLUTION

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ABSTRACT:

In these last years employment and spreading of GPS real-time kinematic techniques is greatly improved. Its application field is extended from traditional topographic surveys to environmental applications. In this work a monitoring project of electromagnetic pollution is shown; this project has been carried out in order to realize an infrastructure of measurement, transmissions, elaboration and management of surveyed data. In particular, the results of a research about the realization of a first prototype of advanced system based on the integration of GPS receivers and other sensors are shown. The research has been carried out in collaboration with "Dipartimento di Ricerche Energetiche ed Ambientali" of University of Palermo and with the "Laboratorio di Fisica ARPA Regione Sicilia". The experimentation has been carried out using a car equipped with roof rack where both an antenna and electromagnetic sensor were installed. The GPS survey was carried out by a integrated palmtop-GPS, linked with an analyser of electromagnetic spectrum, in broadband or not. Well than, a GIS has been created in order to show some thematic maps which represent the distribution of electromagnetic pollution and accuracy positioning.

1.INTRODUCTION

The need for setting up a project in urban environment for managing environmental parameters, like electromagnetic field, pointed out the issue of analysing data which vary continuously and sometimes suddenly, both in space and time.

For this reason, it has been deemed useful to test a mobile monitoring system capable of surveying both position and environmental parameters, at given time intervals, even one second intervals.

For this purpose it has been particularly useful to identify specific pathways where one could repeat measurements at different times.

As a matter of fact the identification of static measurements only, corresponding to more sensible objectives, such as schools and hospitals, enables to know data only for punctual observations, limited to a certain instant or time interval. Repeating measurements in time and extending them in space is quite complex on the realization-logistic point of view and exceedingly heavy if compared with expected results.

Moreover, a static measurement of these values entails the need of identifying some interpolators suitable to accurately and punctually describe the real situation of the measured environmental parameters.

Urban zones also are hallmarked by several sources of electromagnetic waves, such as power lines, radar installations, radio and TV repeaters, DECT repeaters for cell phones and many other electric appliances, even in households where there are unshielded power circuits.

Whilst other pollution forms immediately generate visible effects (bad smells, smokes, vapours, foams), electromagnetic pollution goes totally unnoticed, due to the absence of signals noticeable by our senses.

2..DESCRIPTION OF STUDY AREAS

During the first phase of the experiment a preparatory study has been carried out for the combined acquisition of positional data - using UTM-WGS84 reference system - and of electromagnetic field in three different test areas, both in urban and extra urban zones; this first period of study was necessary to better structure the system and calibrate instruments.

At the beginning, survey areas have been defined based on the possibility of identifying *in situ* medium-high electromagnetic field values; for this reason the following areas have been chosen: the provincial road SP5, touching the municipality of Altofonte (PA), near the metropolitan area of Palermo, the way leading to radio TV and cell phone reception and transmission antennas located on the top of Monte Pellegrino - Palermo - and a urban zone, defined by the axis "Piazza Alcide De Gasperi-Via Libertà-Stazione Centrale-Via Roma-Via Marchese di Villabianca" within the urban perimeter of the town, where there is a high building density.

These three surveys have been carried out between March and July 2005.

In the second half of October with more hardware and software equipments a greater measurement activity has been carried out in a significant area of the town of Palermo, with daily measurements, carried out in the afternoon, to verify data variability over time.

These measurements have been carried out on the way linking Via Basile to Viale Regione Siciliana, up to Via Belgio junction, and continuing through Viale Strasburgo, Via Croce Rossa, up to Piazza De Gasperi and to Viale del Fante, where the town football stadium is located.

During the definition of the itineraries it has been taken into due account the possibility of monitoring those area of the town with at least some objectives sensible to electromagnetic radiations, such as children's schools and hospitals, but this choice has not been always mandatory.

As a matter of fact, this study has been designed to describe, in some sample areas, the trend of electric field as a function of the position on maps, and to be extended afterwards to most metropolitan area of the town.

It has been tried, where possible, to analyse pathways where road infrastructures had a geometry proper to avoid loss of GPS signal, (i.e. without obstacles such as trees or in urban canyons); pathways with narrow roads have been nevertheless taken into account too.

3.USED EQUIPMENT

Different kinds of equipments have been used depending on the measurements to carry out: for the preliminary ones, performed in Altofonte, Monte Pellegrino and in the first urban pathway, the used equipments were: an integrated GPS system, consisting of a *Topcon GNSS Turbo G II* receiver and a *HP iPaq* palmtop, equipped with the operating system *Windows CE* with *Meridiana CE* data management software; this solution enables the user to replace the palmtop with a more performing one, maintaining the same GPS receiver.

The selected receiver can use signal coming from either GPS or GLONASS satellites; it is a 50-channel receiver, capable of decoding the signal on L1 band and WAAS/EGNOS correction.

The positional accuracy declared by the producer is centimetric in post-elaboration and sub –metric in DGPS. It's equipped with 64 MB SRAM and 32 MB ROM.

To improve signal reception and above all to exploit GLONASS satellites as well, it has been deemed appropriate to use a *Topcon Legant-A* antenna instead of the built-in GPS receiver antenna; this latter has been fixed to the top of the transport through a magnetic connection.

The measurement chain for electromagnetic fields used for the experiment consists of an acquisition instrument *PMM 8053A* connected through a optical fibre cable and an optic *PMM OR-03* repeater to the electric field sensor *PMM EP-330*; this latter sensor has been strongly fixed to the top of the car through special bars and a wooden (non conductor) board in order to avert it enough from any car appliances.

Data obtained from the two equipments have been separately calibrated and acquired (information about coordinates for the palmtop and electric field value for the spectrum analyser), so they have been post-processed based on the acquisition time with a *Microsoft Excel* database, for further elaboration in GIS environment. In this way, a first prototype of the kinematic measurement system has been tuned up, with the drawback of needing two survey and measurement systems and of performing several elaboration in order obtain time alignment of collected data.

Furthermore, to be able to improve result presentation and above all because pathways described by the different GIS instruments trajectories had to be automatically compared, the experimentation carried out within the urban area of Palermo in the second half of October has been developed using two receivers: a *Trimble* palmtop, the *GeoExplorer®* series, *Geo XT*, combining a *GPS Trimble®* receiver with a palmtop with *Microsoft Windows® Mobile™ 2003* for Pocket PC and a *Topcon Legacy H* geodetic receiver, with *Legant-A* external antenna.

The Trimble receiver has 12 channels, with the possibility of WAAS and/or EGNOS integrated correction, whilst the positional accuracy declared by the producing company is sub-metric in post elaboration with elaboration software *Pathfinder*, release 3.10. It has been used a flash memory of 512Mb.

The other GPS receiver used for the experiment, namely *Topcon Legacy E and H* receivers, with 40 GPS/GLONASS L1 channels and 20 L1+20 L2 GPS/GLONASS channels, equipped with two *Legant-A* antennas, were available at the "Dipartimento di Rappresentazione".

Therefore it has been possible to define some precision values of the trajectories of the car where the two receivers were installed.

The used data management software were *TerraSync™*, release 2.52 for *Trimble Geo XT* palmtop, *Pinnacle* rel. 1.0 e *Meridiana 351*, for *Topcon* receivers.

With the objective of improving sensors connections modalities, an appropriate support bar for equipments has been designed, using a wooden board strictly fixed to the top of the car through two metal-magnetic plates; one sensor has been positioned at one extremity and the other in the middle; the first has been also placed for being exploited for the *Legant-A Topcon* antenna positioning, while the second not only grants the needed adherence to the top of the vehicle, but also, due to the presence of a triangular metallic plate, permits the adhesion of the external magnetic antenna of *Trimble* palmtop.

The measurement chain for electromagnetic fields used for this second experiment consists only of the *PMM OR-03* optic repeater and of the electric field sensor *PMM EP-330*, directly connected through a optical fibre cable to the serial port of the palmtop receiver, which enables to manage and control with the on board software up to two external sensors. Proper transmission commands have been implemented for the definition of environmental parameters values. Thus, through the PC receiver and the electromagnetic field sensor, it has been possible to carry on the acquisition of experimental data.

4.SURVEY DESIGN

With the above described equipments, different surveys pathways in urban environment have been designed, in a way enabling to carry out monitoring campaigns; pathways have been defined both using the GPS navigation mode and code measures, besides postprocessing data using a base corresponding to the newer permanent station of the "Dipartimento di Rappresentazione" of the University of Palermo, with coordinates referred to four IGM 95 nearest points (Monte Cuccio, Palermo Porto, Cefalà Diana and Monte Catalfano). Files of the base station have been exported also in

Standard RINEX format, to enable *Trimble* receiver to perform postprocessing operations.

As for sampling times, after having performed surveys with 5 seconds intervals, a time unit of one second has been preferred, given the great variability of electromagnetic field results.

Moreover, as cartographic base for the first experimental phase (survey campaigns of Altofonte, Monte Pellegrino and the town of Palermo), digital ortophotos of the *Terraitaly* project (carried out by *Compagnia Generale Riprese Aeree* of Parma) with a nominal 1:10000 scale have been taken as a reference. For the second part of the experiment, a Pan-Sharpened *IKONOS*-2 satellite image of Palermo has been used: the original image is of *"Geo-Product"* type, the most economic among *IKONOS* images, with 1 meter geometric resolution.

This image has been chosen because in the multispectral ones many details can be seen through colour difference, but they cannot be clearly pointed out due to the low geometric resolution. In panchromatic images, instead, even if objects are clear and with defined outlines, they cannot be clearly classified due to the lack of colours spectrum information. In Pan-Sharpened images, on the other hand, a good colour reproduction with no significant chromatic distortions is observed, enabling an optimal visualization of details, such as the edges of buildings and streets.

The real advantage of the second part of the experiment, as already mentioned, laid precisely in the possibility of checking data about the values of the electromagnetic field directly from the *Trimble* GPS palmtop; this operation has been performed thanks to the software installed on the *GEO XT* receiver, enabling it, through appropriate alphanumeric strings, to request and record the total field value directly to the optic *PMM OR-03* repeater and to the electric field sensor *PMM EP-330*.

Thus, as it results from the sensor programming commands, *PMM OR-03* has been connected to the palmtop receiver with a optical fibre through the serial connectors supplied by manufacturers, so that the field measurement instrument can be remote controlled and queried.

Serial communication between *PMM OR-03* and the PC is obtained through RS232 standard.

In this way, request and visualisation commands have been beforehand put in the *Trimble* palmtop and COM1 has been assigned to communication with the internal personal computer for data transmission.

In this phase sampling values of one second have been set for electromagnetic field requests, through the pull-down menu of the laptop.

Thus, through available alphanumeric strings capable to obtain directly - without postprocessing - the values of coordinates and of the electric field measured at the same time, couples of files have been obtained (one with the *Topcon* receiver, the other with the *Trimble Geo XT* receiver), which have been further elaborated to determine the correct position of coordinates in GIS environment.

The assumed comparison trajectory is defined by the minimum deviations in E,N, components, obtained by GPS *Topcon* receivers, considering kinematic solution.

A special routine in *AutoLISP* has been defined for comparison operations between the coordinates traced by the two receivers; this routine enables to identify directly the differences in coordinates between the two trajectories, in a way they can be automatically recorded on a file with *.txt* extension, and easily elaborated with a *Microsoft Excel* spreadsheet.

In CAD environment some line segments have been drawn, forming a grid with regular pace: first offset elaborations have been made, respectively, at 10 and 50 m; it has been chosen to operate with the average value, equal to a 25 m offset.

5.ANALYSIS OF RESULTS

Elaborations in GIS environment have been made with the available cartographies of the selected areas and with data taken from measurement instruments (coordinates and electromagnetic field).

The obtained solutions refer to the representation of thematic maps, showing the variations in continuum of the electromagnetic field as a function of the different pathways chosen for the survey (with *ESRI ArcGIS* software) and the analysis of results obtained with GPS positioning (performed with *Microsoft Excel*).

For the representation of thematic maps, forecasting models have been used, applying geostatistic methods such as *IDW*, for representing data, using the *ArcGIS Geostatistical Analyst* software module. This interpolator weighs more the points which are closer to the location, than farther ones, from which the name of "inversely weighed distance".

Starting from punctual measurements of electric field values with continuous measurements, assessment surfaces have been arranged, showing the spatial distribution of surveyed data, as shown by Figure 1.

From the analysis of the survey performed on the site of Monte Pellegrino, it is evident that the value of electromagnetic field is always above the 6 volt/m threshold imposed by national regulations; in some points of the site the value exceed 20 volt/m, value which must never be reached, not even for an instant.

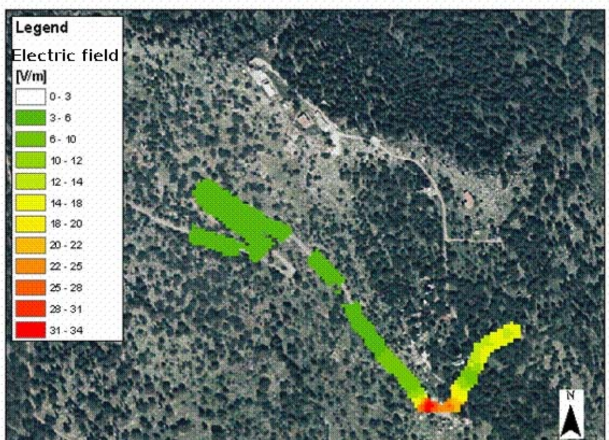

Figure 1. Trend of the electric field over Monte Pellegrino

Since, on the other hand, the same regulations do not provide for surveys carried out with kinematic methods, further additional static campaigns can be performed, in order to assess, in 6 minutes acquisition intervals, the average value of the electric field.

Results obtained in this way can be described as veritable preliminary environmental monitoring activities for those areas where the exceeding of threshold values can be reasonably predicted.

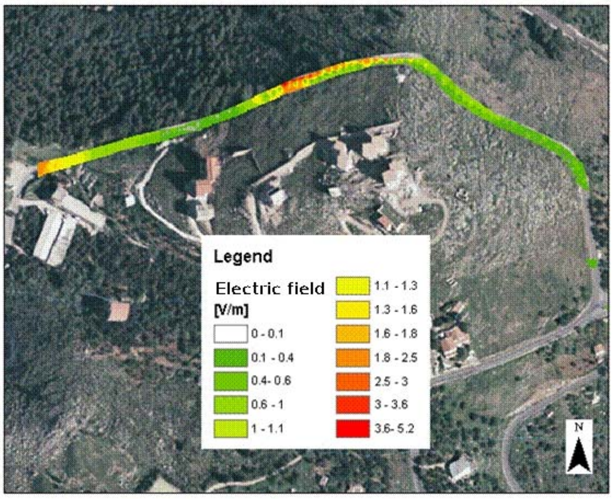

Figure 2. Trend of the electric field over Altofonte

As for the surveys carried out on the Altofonte (PA) site, on the other hand, values obtained for electromagnetic field are slightly inferior to the ones defined by law (5.20 volt/m max); it will be necessary, in this case, to perform additional static measurements to check that threshold levels are never exceeded, at various times in the day, and in the following periods of the year, as shown by Figure 2.

Moreover, in the *ArcGIS* software punctual values representations have been also used, with the advantage of not requiring interpolators, allowing at the same time thematic representation.

From the survey performed in July in the urban area of Palermo, again with the *Topcon Turbo G II* GPS receiver and the electromagnetic spectrum analyser, values under the threshold have been obtained, except for some positions near Piazza Alcide De Gasperi, where maximum peaks of 10,18 volt/m have been recorded.

As for other measurements carried out between September and October with the integrated palmtop *Trimble Geo XT* receiver, it can be said that results in terms of electromagnetic field values are always below the by-law threshold, as shown in Figure 3.

In this case the comparison has been carried out among equal pathways, but at different hours of the day (daytime and afternoon); almost identical values are obtained for coordinates, where the values of electromagnetic field slightly differ among them, with peaks ranging from 2,24 volt/m in the morning and 2,20 volt/m in the afternoon.

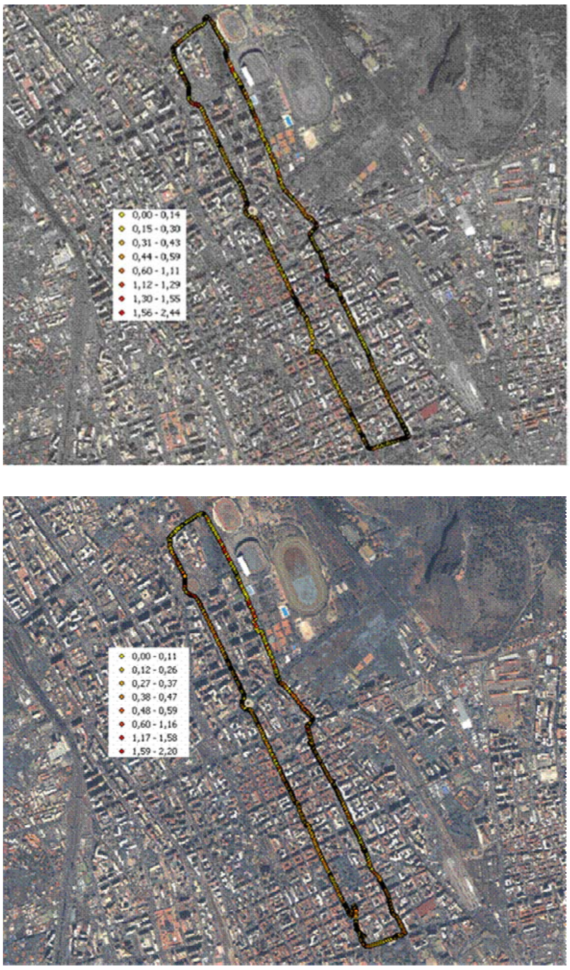

Figure 3. Trend of the electromagnetic field over Palermo

In these pathways the values of electromagnetic field are still slightly different among them, ranging from variable peaks of 2,32 volt/m in the second, 2,11 volt/m in the third and 2,23 volt/m in the fourth pathway. This latter has been designed in correspondence with some districts neighbouring the university campus: the results of all measurements are shown in Table 1.

Pathway	Field [V/m]
1st daytime	2,44
1st afternoon	2,20
2nd	2,32
3rd	2,11
4th	2,23

Table 1. Maximum values in urban area

The experiment allows to evaluate the deviations in the components of horizontal and vertical coordinates, as assessed by GPS instruments.
First of all, these results must be divided on the basis of the surveys carried out between March and July (*Topcon Turbo G II* receiver) and the ones performed between September and October (*Trimble Geo XT* receiver).

Actually, surveying modalities differ between the two groups: the ones performed with *Turbo G II* have been made without checking with other geodetic receivers and they have been performed in navigation mode and with EGNOS differential correction; vice versa, for the ones performed with *Trimble Geo XT* also in navigation mode and with EGNOS correction, those had the possibility to be checked in the development of trajectories through the *Topcon Legacy H* receiver, located within the vehicle and connected through a magnetic connection to the antenna on the top of the vehicle.

In this second case, receivers antennas have been placed at a known distance (0.62 m), measured with extreme precision through a total *Leica TCR 1105* total station, equipment of the “Dipartimento di Rappresentazione” of the University of Palermo.

For the measurements carried out with *Turbo G II* it has not been possible to perform any control, also because the same instrument returned horizontal and vertical standard deviation values, through the *Meridiana 351* software.

The trends of horizontal and vertical deviations have been displayed in dispersion diagrams and histograms have also been produced, grouping the percentages of deviations within four intervals: the first ranging between 0 and 1 m, the second between 1 and 2 m, the third between 2 and 5 m and eventually the last with values above 5 m (Figure 4).

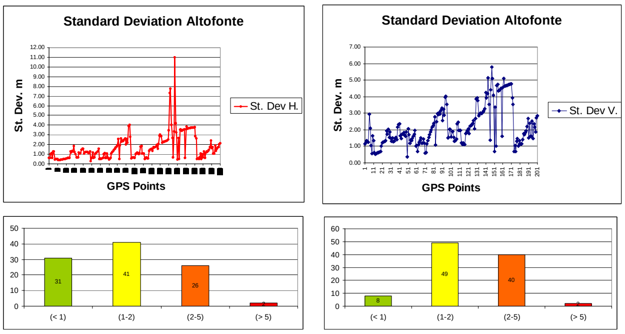

Figure 4. Trend of the deviations (Altofonte)

Diagrams refer both to data with real-time differential EGNOS correction by GPS equipments and to data obtained in navigation mode.

As for the survey carried out in Altofonte (PA), 201 GPS positions have been measured, with an instrumental height of the sensor of m 1.234; for horizontal components standard deviation values ranging from 0.29 and 11.01 m have been obtained (average value 1.66 m), whilst for vertical component values range from 0.35 to 5.79 m (average value 2.18). In the survey carried out above Monte Pellegrino, 1951 GPS positions have been measured, again at the instrumental height of 1.234 m, obtaining for horizontal components standard deviation values ranging between 0,02 and 34,67 m (average value 1.66), and for the vertical component values ranging between 0.02 and 36.14 (average value 2.25), has shown in Figure 5.

These figures show that the precision of measurements carried out with GPS instruments falling within a interval equal to one metre (benchmark for EGNOS correction) is equal, respectively, to 31% and 25% for the horizontal components and 8% and 17% for the vertical one.

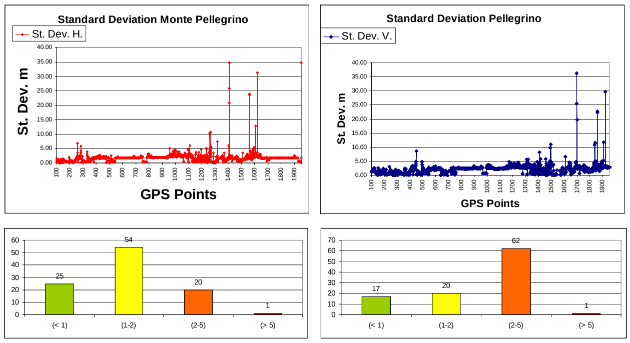

Figure 5. Trend of the deviations (Monte Pellegrino)

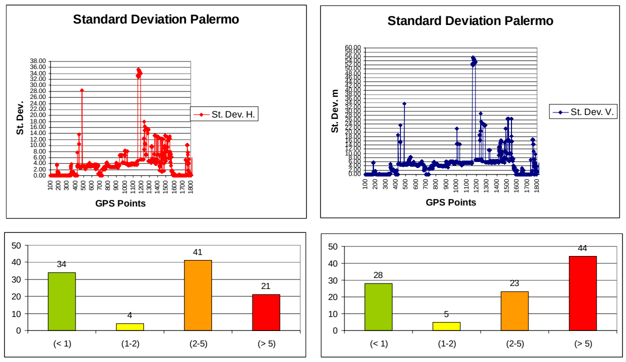

Figure 6. Trend of the deviations (Palermo)

A further comparison has been possible with the survey carried out within the urban area of Palermo, both in navigation mode and with EGNOS differential correction: respectively, 1891 and 1927 GPS positions have been measured, at a sensor instrumental height of 1.388 mm, obtaining for the horizontal components standard deviations values ranging between 0.01 and 35.38 m (average value 3.86 m), and for the vertical component values range between 0.01 and 55.60 m (average value 5.59) with EGNOS correction; for measurements carried out in navigation mode, standard deviation values ranging between 0.02 and 42.27 m (average value 4.51 m) have been obtained for horizontal components, and for the vertical component value range from 0.03 to 42.50 (average value 7.28), as shown in Figure 6. It can be seen that the precision of measurement of the GPS instrument within the benchmark interval for the EGNOS correction corresponds, respectively, to 34% and 2% for horizontal components and to 28% and 1% for the vertical one. With respect to the horizontal component and to EGNOS correction the obtained percentages are displayed in Table 2, where the results of the measurements are shown in four interval classes.

	Position accuracy			
Interval [s]	**(<1)**	**(1-2)**	**(2-5)**	**(>5)**
Altofonte	31	41	26	2
Monte Pellegrino	25	54	20	1
Palermo	34	4	41	21
Mean %	**30**	**33**	**29**	**8**

Table 2. Results of *Topcon Turbo II*

As for the results obtained with *Trimble Geo XT*, the trajectories of the acquisitions in navigation mode, with post processing of data from the newel post fixed base station and WAAS-EGNOS system correction have been compared to the trajectories traced by the *Topcon Legacy H* receiver, with kinematic solution (Figure 7).

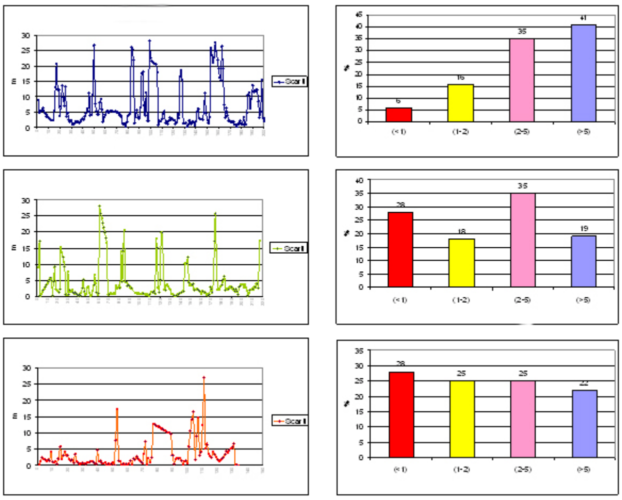

Figure 7. Comparison between *Geo XT* pathways (Navigation, Posprocessing, EGNOS)

Comparisons have been made only for the horizontal components. It can be observed that data distribution is such that, switching from navigation mode to postprocessed one, percentages arise from 6% to 28% for the first class (0-1 m), remain almost unchanged, between 16% and 18% in the second one (1-2 m) and 35% in the two cases (2-5); a considerable reduction, from 41% to 19% is obtained for the last component (more than 5 m).

It can be moreover observed that, switching from the postprocessed mode to the EGNOS corrected one, the same percentage (28%) is obtained in the first class (0-1), a considerable improvement is obtained in the second class (from 18% to 25%, class 1-2) and a reduction in the third (from 35% to 25%, class 2-5); percentage remain almost unchanged within the fourth class (19%-22%)

On the basis of results obtained in EGNOS mode, only this type of differential correction has been chosen for the other pathways.

Results can be summarized as percentage deviations trends, in Table 3.

	Position Accuracy			
Interval [s]	**(<1)**	**(1-2)**	**(2-5)**	**(>5)**
1st	52	25	20	3
2nd	43	24	22	11
3rd	47	31	17	6
4th	42	22	28	8
Mean %	**46**	**25,50**	**21,50**	**7**

Table 3: Results with *Trimble Geo XT* receiver

This table shows that percentages vary from 42% to 52% for the first class (0-1 m), from 22% to 31% for the second (1-2), from 17% to 28% in the third (2-5) and from 3% to 11% for the last class (more than 5 m).

6. CONCLUSIONS

The objectives of this experiment were: the definition of a system for data acquisition and elaboration, the monitoring of environmental parameters, namely of the value of electromagnetic field in test areas and, eventually, the assessment of positional accuracy of GPS (palmtop or not), related to the differential WAAS/EGNOS technique.

After the first experiments carried out with the *Topcon Turbo G II* receiver and the *PMM 8053 A* spectrum analyser (separately acquiring respective data) an integrated measurement apparatus has been prepared, through the setting of command strings within the *Trimble Geo XT* palmtop.

It became thus possible to consult, acquire and store all data (position and electric field) within a single measurement instrument.

As for environmental monitoring, trends of electromagnetic field have been identified in sites located at Monte Pellegrino, Altofonte and in several urban areas in Palermo; it is evident that in the first site the value of field remains always above the threshold value of 6 volt/m imposed by national regulations, even exceeding 20 volt/m, value which must never be reached, not even for an instant. In the second site (Altofonte), on the other hand, the obtained electromagnetic field values are slightly below the ones fixed by regulations (max 5.20 volt/m)
In urban area of Palermo values obtained are always below by-law threshold (max 2.49 volt/m), except for some maximum peaks of 10.18 volt/m. Repetitions of measurements at different time intervals confirmed the acquired values.

With these results it is possible to affirm that further integrative campaigns can be carried out, both of kinematic and static kind, to identify, in appropriate acquisition times, the value of the electric field and perform the decontamination of the sites.

Moreover, analyses have been carried out enabling the evaluation of the GPS (palmtop or not) positional accuracy, studying the differential WAAS/EGNOS technique, postprocessing corrections and variations in navigation mode.

Performed experiments showed that the good result obtained through EGNOS correction, enabling to obtain precision levels compatible with planimetric precision (1 metre), with an average percentage ranging, for the used instruments between 30% and 46%; expanding results to 2 meters values, the result in terms of precision ranges from 66% to 71.50%.
Similar results are obtained using corrections given by a fixed basis and postprocessing, while precision values compatible with the use of *GIS* systems are also obtained using a navigational system.
Research can be further developed defining a system for the acquisition and elaboration of data, where these latter can be transmitted in real time, so to be able to evaluate on a remote server the variations in the electromagnetic field at different times.

Finally, through the formulation of complex calculus algorithms, it will be possible to estimate the signal/rumour ratio (*SNR*) of GPS instruments, in a way to evaluate it in correspondence to the values of the electromagnetic field and ascertain the existence of interrelations between the measured field and *SNR*..

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