# A teaching experience about a GPS network

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**ABSTRACT**

This paper deals with a teaching experience carried on at the Politecnico di Milano Faculty of Engineering, town of Lecco Branch Office, during the surveying teaching. The students, with the teachers help, have planned, projected, measured and adjusted a GPS network in the town of Lecco area, learning the use of GPS technology and of Microsoft Excel to do a least squares adjustment. The teaching experience is here described and the results of the students works presented.

## 1. INTRODUCTION

The teaching experience here described, has been carried on with students of the fourth year of the Faculty of Civil Engineering of the Politecnico di Milano (Lecco Branch Office). About 30 students 23-25 years old, almost all the students attending the Surveying course, have been involved in this experience.

One professor and one researcher, with a Ph.D. student help, organized and assisted the students. The aim of this experience was to test the teaching method based on the idea that is much easier to learn surveying doing surveying. In only four months infect, the students should learn surveying; this means, leveling methods, surveying with total stations, GPS, DATUM problems, least squares method, cartography and some information about photogrammetry and GIS.

Instead of trying to create surveyors giving "so much information as possible in this short time", it was decided to give them a large information spectrum about the main topics and to insist on the more advanced technologies, making some practical experiences of planning, measuring and adjusting a network. The aim was to try to give the students the *"felling of surveying"* as the sense of the measures accuracy and redundancy, the problems of networks planning and measuring...

The purpose is that the students are going to have, in their future study and work, the correct approach to the surveying problems, that means having the basic information learned in this course as basis for peculiar studies and in detail applications.

## 2. THE SURVEYING COURSE

The teaching schedule was so organized and divided:

| | |
|---|---|
| 1- Statistics and data analysis | 20% |
| 2- Surveying instruments (Level, total stations, GPS receivers) | 20% |
| 3- Cartography and DATUM | 20% |
| 4- Surveying methods | 10% |
| 5- GPS experience | 30% + extra time |

The schedule time corresponds to 160 hours; extra time given by some students and by the teachers can be estimated in about 30÷40 hours.

The main topics of the GPS experience have been:

- the GPS use
- the GPS network project,
- the sessions planning,
- the data analysis and measures least squares adjustment.

As before said the main task of this GPS campaign was to introduce the students into real surveying experiences. The students worked on real problems, applying the knowledge learned at lesson; at the same time this experience provided a link between the University and the town of Lecco. Infect the City council gave to the University the WGS84 coordinates of three IGM95 (zero order GPS Italian network) vertex, placed around Lecco to be use as control points, and made some monuments in Lecco.

The title given to the work has been: "Evaluation of Lecco Town subsidence using GPS technology". It is important to notice that the subsidence evaluation in Lecco is quite important, being the Town on the shore of Como lake.

## 3. WORK ORGANIZATION

Nobody was forced to joint to the GPS experience (need of extra time) but almost all the students were glad to attend the work. The students were organized in groups of 2-3 people; the groups were made by the students themselves, and the same problems were given to all the groups.
They had to create some *Microsoft Excel* sheets and macros, and had to project a GPS network, choosing the geometric scheme that is the vertex and the baselines to be measured.
The 9 proposed net schemes were later discussed all together and one was chosen for the measurement experience; before all the students had to learn the use of GPS receivers. Each group had the task of GPS measuring operations for about half a day.
So the entire work done by all the 9 group can be summarized in these main steps:

1- To create "software" for solution of coordinates problems, using *Microsoft Excel* worksheets.
2- To project the network.
3- To make an a priori least squares analysis of the network proposed by the group itself (Using *Microsoft Excel* worksheets).
4- To learn the use of GPS receivers (*GEOTRONICS GEOTRACER SYSTEM 2000*) and to measure the network for half a day.
5- To prepare a final report about the experience.

The data processing and final network adjustment have been carried on, for time reasons, only by the teacher staff with the help only of the more interested students (10).

## 3. FIRST STEP: SOFTWARE FOR SOLUTION OF COORDINATES PROBLEMS

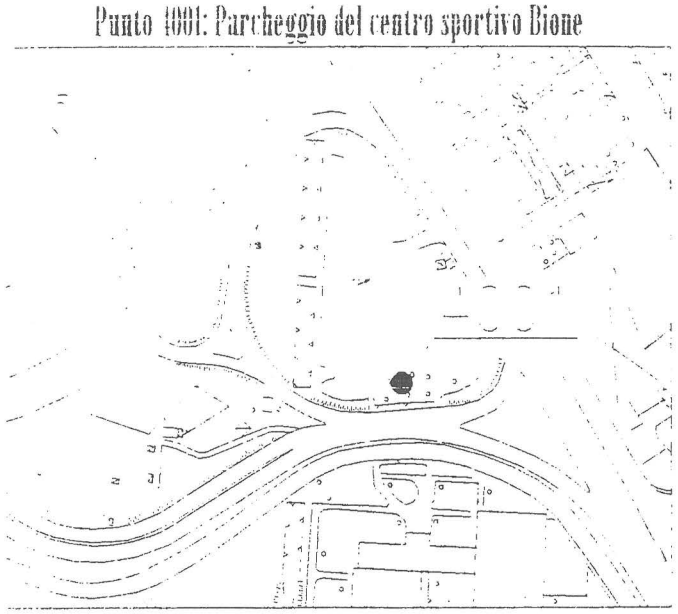
As first step during the first part of the course, the students were asked to make four "software" in the form of *Microsoft Excel* worksheets. These software had to solve the following problems:

1- Least squares 7 parameters transformation, to allow moving form $(X,Y,Z)_{WGS84}$ coordinate system to $(X,Y,Z)_{HAYFORD\ RM40}$
2- Hirvonen formula to move from (East, North) map coordinates to $(\varphi, \lambda)_{ellipsoid}$ and from $(\varphi, \lambda)_{ellipsoid}$ to (East, North) map coordinates.
3- Transformation from $(X,Y,Z)_{WGS84}$ to a local cartesian system
4- Transformation to move from $(\varphi, \lambda, h)_{ellipsoid}$ to (X,Y,Z)

These software were later used, by each group, to evaluate from maps the approximate coordinates in (X,Y,Z) system and to move the adjustment results obtained (X,Y,Z) to $(\varphi, \lambda, h)$ or to (East, North) map coordinates.

## 4. SECOND STEP: THE NETWORK PROJECT

As second step the students had to project the GPS network. Using 1:2000 and 1:10000 map scales they had to define the position of 4 control vertex inside Lecco town and how to connect the control points to the three IGM95 points placed (10-20 Km) outside the town.
The (X,Y,Z) control points coordinates had to be evaluated, as approximate values, using the East, North map coordinates and the software described in par. 3. Picture 1 show how one group described one control point position, using as support the numeric town cartography (1:2000).



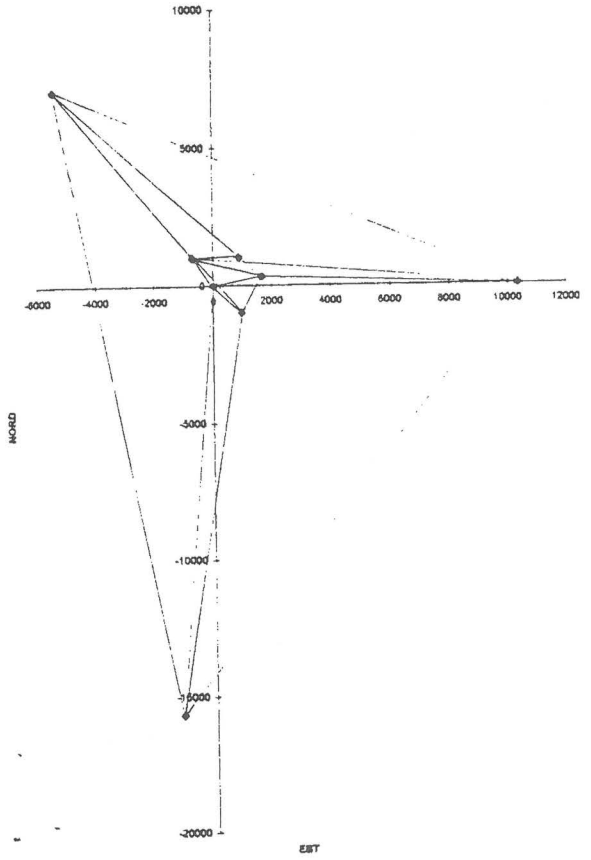

Picture 1: GPS control point 4001

The network proposed by the students had to follow these characteristics:

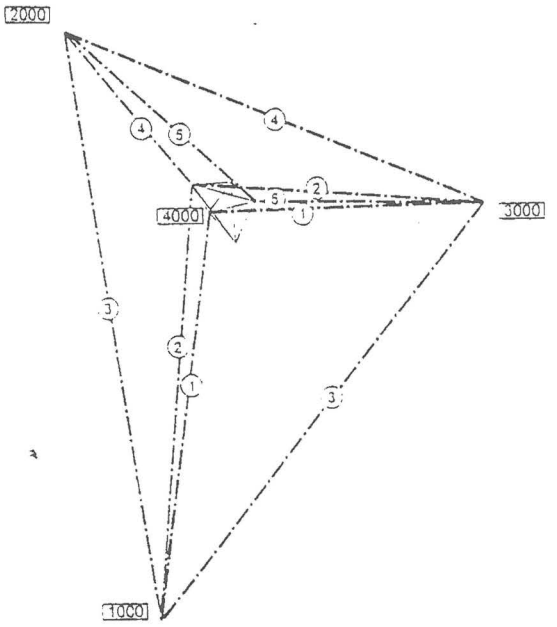
- a network scheme with 8 points:
  - 3 *IGM95* points (with the position a priori well known),
  - 1 points known in height,
  - 4 control points to be placed in Lecco town;
- the control points in Lecco had to be also good GPS points;
- a network scheme had to be measurable in two days campaign, (6 hours working time), using a static 45 minutes approach and considering also the time lost to move the receivers from one station to the next one;
- the network accuracy to be reached was fixed in ± 0.03 meters.

The students had to plane the baselines to be measured and the work planning for each receiver;

Picture 2 and Picture 3 show a couple of network geometry proposed by two different groups of students.




Picture 2: The global network as proposed by group 2




Picture 3: The network inside the town, as proposed by group 5.

## 5. THIRD STEP: THE NETWORK A PRIORI LEAST SQUARES ANALYSIS

Each group had to test the accuracy, reachable by only a part of its proposed network, using an a priori least squares analysis; the reason of this was to avoid problems due only to the matrix sizes. The small network tested had to be composed by 4 points and at least by 6 baselines. The small number of baselines and of unknowns, allowed each group to make a *Microsoft Excel Worksheet* to do the a priori least squares analysis. The stochastic model to be used had to be as follows, where x, y and z must be considered as local oriented Cartesian system, with z close to the vertical direction:

$\sigma_x = a + b * \text{Distance}$

$\sigma_y = a + b * \text{Distance}$

$\sigma_z = 1.6\ (a + b * \text{Distance})$

with $a = 0.01$ meters and $b = 0.002$ m/Km. One points had to be considered as constrained.

To the $\sigma_z$ was given a model similar to the model studied in different subsidence experiences

Each group had to discuss in a written report the results of its a priori analysis and to observe and explain the results obtained for the full network, using a professional a priori least squares software - *NETGPS* developed in the Department I.I.A.R. Politecnico di Milano - with the help of the teachers. Picture 4 show the "A" matrix of one of the worksheets built by the students.

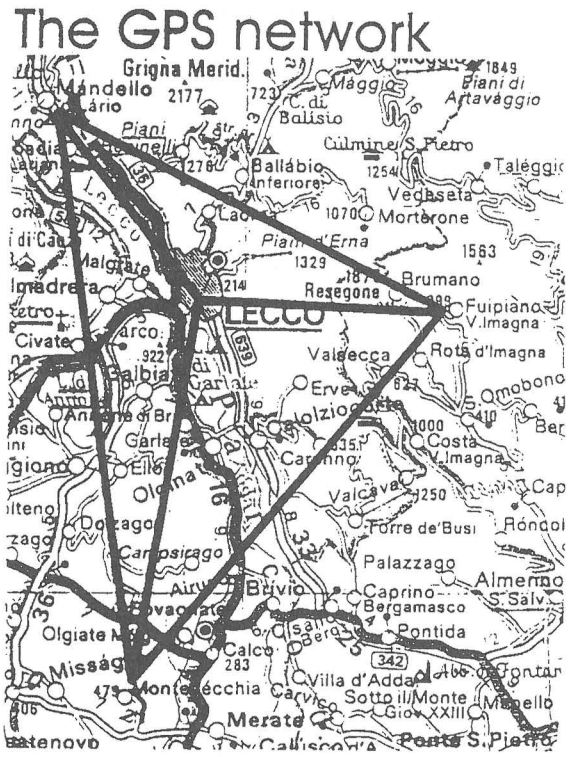
All the networks proposed by the 9 groups were at the end analyzed with the teacher that decided the final geometry of network.

| E1000 | N1000 | h1000 | E2000 | N2000 | h2000 | E3000 | N3000 | h3000 | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | -1 | 0 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | -1 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | -1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | -1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

Picture 4: "A" matrix of one of the worksheets for the least squares a priori analysis

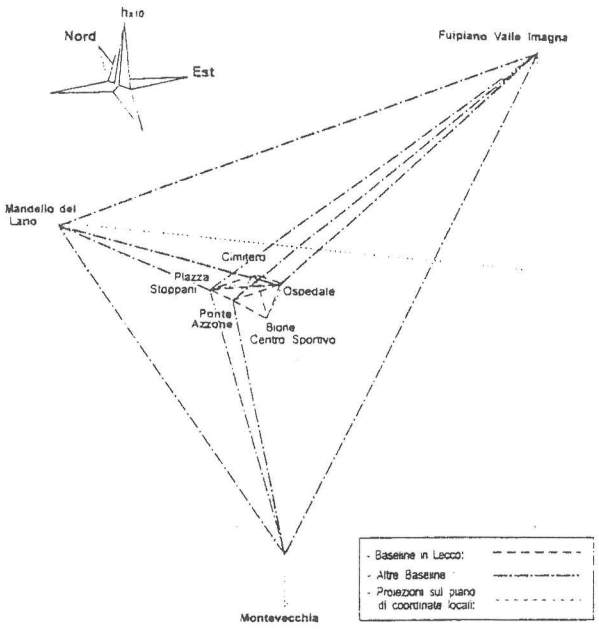
## 6. FOURTH STEP: THE NETWORK MEASUREMENT

The finally chosen network, (picture 5), was composed by 8 points connected with 15 baselines (picture 6).
Three *GPS L1/L2 GEOTRACER SYSTEM 2000 (GEOTRONICS)* receivers were used, free lended by *AGEOS* Agrate (Italy). The network was measured in two days and all the 9 groups participated to the experience. The sessions were of 40 minutes for the baselines between Lecco points and IGM95 points (Mandello Lario, Fuipiano Valle Imagna, Montevecchia) and 30 minutes for the baselines connecting the points in placed in Lecco.




Picture 5 The network connected the control points placed inside the town of Lecco and three IGM95 points (WGS84 coordinates known).

Only the measures of one session ware not registered in one receiver, for an error using the memory card of the receiver; all the other sessions were successfully registered. The links between the different stations were obtained using cellular phones carried also by the students and the groups moved with their own cars to the different GPS points. Every group was assisted by the Professor, the assistant or by a Ph.D. student.




Picture 6: The final network

## 7. FIFTH STEP: THE FINAL REPORT

After the experience every group had to prepare a written report and a floppy disk containing:

- the full description of the work;
- the used *Microsoft Excel* Worksheets and Macros;
- the description of the criteria used to project the network. The project of the network;
- the description of the simulation process, and the used *Microsoft Excel* worksheet.
- the planning of the measurement campaign;
- everything that the group considered as important.

The quality of the reports was quite different from a good level to a minimum one.
The final exam of the course consisted on an oral discussion about the GPS experience and about one other topic of the course.

## 8. THE NETWORK ADJUSTMENT

There was unfortunately no time to make the network adjustment. During two lesson the assistant showed to the students the baselines evaluation using software *Geotracer (GEOTRONICS)*. Some tests of triangles closures and an examples of rigorous least squares adjustment was carried on using NETGPS software.
Few students helped the teacher to finish the network adjustment, obtaining a final r.m.e. on the x,y,z local coordinates lower then ± 35 mm.

## 9. CONCLUSIONS

This teaching experience has shown that is possible, also in a short time, to organize an "important" and complete work on field with the students. Few resources are required, if the students show interest, but the work must be very well organised at the beginning of the year, in the way to be able to finish all the work (with the network adjustment too).
The students show a very high level of interest, and seems to have learned a lot. It must be found a way to give to each group a different task, to avoid a global cooperation of the students, with the results of very different levels of study among the different groups of students. The groups have also made a small experience on photogrammetry. They have started from the GPS points, with a total station, to measure the control points on some facades in a Lecco Square. This second experience has been reported in (1).

## 9. REFERENCES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