Chair:
**Prof. Fernando Sansò**

# DOCTORAL PROGRAM IN GEOMATICS AND INFRASTRUCTURES

The Doctorate of Geomatics and Infrastructures continues the tradition of the previous Doctorate in Geodesy and Geomatics, dating back to the first cycle of doctorates in Italy of the years 1983-86. Thus, according to the vision of the Doctorate School of Politecnico di Milano, we are working now within an interdisciplinary environment.
The original field of geomatics, which in any way was already quite extended, has become even larger, enriched by disciplines that beyond defining the shape of the "Surface of the Earth" look at its use too as support of human activities, in particular infrastructures (road, railways, airports, etc.) and even at its stability, due to the interaction with first layers of the earth structure (applied geology). So, viewing the field of activity of the doctorate in terms of heights, we could say that we produce research on topics like: satellite geodesy (maintenance of global reference systems, orbit determination, global gravity field recovery), satellite earth observation (satellite positioning – GNSS remote sensing, high resolution imaging), airborne observation (aerogravimetry, digital photogrammetry and image analysis, LIDAR and SAR surveying), ground surveying and mapping (traditional and modern surveying, topographic data bases, geographic information systems), cultural heritage surveying (determining and archiving the shape of architectural and artistic works), structural control (surveying and controlling the geometry of structures and infrastructures at submillimiter level), navigation (inertial and satellite assisted navigation), traffic modelling and control (roads safety measures), designing, building and repairing infrastructures (technology and security on construction sites), monitoring the slope instability (identification, characterization and reconstruction of slopes dynamic), detecting geodynamical signals (crust deformation monitoring, subsidence, gravity field monitoring).
The doctorate is articulated into 3 branches: geodesy and geomatics, surveying and geomatics, infrastructures. It offers to students high level courses in the different branches for 60 credits, and supports their participation in international research activities. After two mandatory courses of overview of geomatics and data processing, students can attend one of the following programs:

**Geodesy-Geomatics branch**
- Data processing 2
- Geomathematics
- Image analysis and digital photogrammetry
- GPS
- Geographical Information Systems

**Surveying-Geomatics branch**
- Local surveying
- GIS: applications
- Remote sensing
- Applied photogrammetry
- Architectural surveying

**Infrastructure branch**
- 15 credits chosen from other branches
- National Summer School on Infrastructures

Furthermore there are elective courses to be chosen among: Satellite geodesy, Gravity field modelling and geoid estimation, DTM generation, Advanced spatial representation, Navigation and kinematic surveying, Geomatics and planning, Road experimental laboratory (advanced course).

Ultimately it steers students in the production of a doctoral thesis. The quality of the work of the doctorate, from courses to the theses, is checked annually by a committee of national and international referees.

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# AUTOMATIC TIE POINT EXTRACTION FROM MARKERLESS IMAGE BLOCKS IN CLOSE-RANGE PHOTOGRAMMETRY

**Luigi Barazzetti**

This thesis presents an automated methodology with an aim to match tie points in different categories of images. The algorithmic implementation of the proposed technique is encapsulated into a software called ATiPE, that being the practical solution obtained.
This work was started few years ago with a simple consideration in mind: there does not seem to be a software adapted for the automated orientation of markerless sets of images. Indeed, the complexity and diversity of image network geometry in close-range applications, with wide baselines, convergent images, illumination changes, occlusions and varying overlap, makes the identification of tie points more complex than in aerial photogrammetry. Therefore, functional commercial solutions (say proven techniques) for automated image orientation and sparse 3D geometry reconstruction from markerless sets of images are still pending.
The entire procedure combines several algorithms of both Computer Vision and Photogrammetry in order to obtain an accurate reconstruction in an automated way. SIFT and SURF are used for a preliminary feature-based orientation, which is then improved by using the FAST interest operator. Indeed, the normal results obtainable with matching methodologies based on scale invariant features are usually worse than those achievable with manual (interactive) measurements.
It becomes necessary to improve (i) the measurement precision of the image points, (ii) their multiplicity, and (iii) their final distribution in the images.
Moreover, images must be used at their original size. An initial image compression is followed by a coarse-to-fine approach to make full use of the acquired data.
The proposed methodology for orienting calibrated images estimates the unknown parameters with the same accuracy as the traditional and manual measurements.
Furthermore the perspective functional model based on collinearity equations allows one to control the results with a rigorous statistical evaluation.
Regarding 3D modelling, it was demonstrated that automated image orientation and surface measurement are nowadays achievable with satisfactory results in terms of accuracy of the geometric models. In fact, the geometric accuracy is becoming more and more important, while aesthetically pleasing visual results are only sufficient for visualisation and VR applications. Different kinds of active optical sensors available today can capture 3D models of terrestrial objects. However, in some situations their high cost, difficult portability and simply their weight might limit their use in practical projects.
Image-based 3D modelling can be then considered as a competitive alternative to active sensors. The surface measurement method, based on a multi-image geometrically constrained framework, is capable of achieving results very similar to active range sensors, demonstrating its great capabilities and potential.
Therefore, automatic image-based 3D modelling of free-form objects is feasible. The entire production process is quite fast and notably more economical than modelling procedures based on laser scanners.
Good metric results were also obtained by combining the photogrammetric image orientation procedure and patch-based MVS algorithms.
This methodology gives accurate and detailed reconstructions of free-form objects. Manual measurement are restricted to a minimum, as a result the automated method can be used by people who are not very expert in the field of CV, photogrammetry, and surveying.
The method is not only limited to pinhole images. Matching with feature-based algorithms and coupled with the analysis of the intrinsic geometry of the data, allows the processing of different kinds of data.
Spherical images, which can be assumed as belonging to a new branch of photogrammetry, can be matched and oriented with a strategy based on a spherical unwarping. The partitioning of the sphere into zones, which are independently matched and then combined, transforms the data into local pinhole images.
Finally, the estimation of the camera poses can be carried out with a mathematical formulation between (i) the centre of the sphere, (ii) image point (on the sphere) and (iii) object point. Therefore, there exists an analogous form of collinearity equations for this category of images.
Laser scans can be registered by using the panoramic images generated from 3D points and their intensity values. Although this procedure aligns a set of scans without using any initial approximation, some limits were found in the case of highly convergent scans. As things stand now, it is difficult to forecast a massive use of such a method in complex practical projects. Further developments are necessary to improve the repeatability of feature-based operators.
Finally, the procedure was adapted to analyse particular sequences of multispectral data. Images taken from the same point with a special camera mounting different filters are related by a homography and can therefore be automatically matched and registered.
The examples proposed in this PhD thesis show that ATiPE can successfully deal with different data acquired with different sensors. Although the main goal is the analysis of large and complex datasets, the pairwise registration concept always remains the core method used for global analysis.
This formulation of the general problem, combined with a successive combination that includes all the original data, makes the whole processing possible with a high degree of automation.
In addition, each specific geometric model used during the pairwise matching phase strictly depends on the intrinsic characteristics of the sensor employed. However, it is remarkable that, even with different data, a relationship between corresponding features can often be mathematically defined as a linear transformation.
Then, this model can be applied for outlier rejection in order to work with datasets that contain partially incorrect matches. Therefore, due to this common formalisation of the matching problem, the proposed solution can be adapted to work with many different categories of images, and it will be used in future works requiring the processing of data acquired with other instruments.

# CITY MODELING IN STOP-AND-GO MODE WITH TOPOGRAPHIC AUGMENTATION

**Costante Bonacina**

The technological problem of the surveying in urban areas by survey-equipped vehicles, commonly known as city modeling with approach mobile mapping, would appear to have solved by analyzing the market offers of hardware and software. The access to those integrated systems is very difficult, because they are expensive.
The approach developed introduces an innovative procedure compared to the classical techniques of city modeling, proposing a return to the traditional surveying tools. The tools are integrated into a platform for surveying that is equipped with a laser scanner and a set topographic target. The vehicle can be "followed" with a total-station. The use of a platform built on a mobile mapping vehicle allows to conduct productive survey sessions in urban environments, in stop-and-go mode.
The work also concerns the use of digital cameras with wide-angle (fisheye) lens for the creation of texture applied to geometric 3D models.
It is investigated the possibility of realizing an hardware-software tool for the automatic calibration of cameras with short lens.
The problem of the survey in urban areas, commonly known as city modeling, approach with mobile mapping could be said, by analyzing the offers of hardware and software essentially resolved. Market systems are present promising solutions that combine with instrumental methods of treatment data, would appear to have resolved the issue of survey of urban area with instrumented vehicles in motion. The stated accuracy, with regard to the final model, is obtained by combination of assumptions and simple estimate of the instrumental error propagation of each sensor.
The commercial systems often offer an integration between sensors positioning, geometric non-contact measurement and acquisition images using digital cameras and camcorders. The color information is used to enrich the geometric model. The access to these integrated surveying systems is also very difficult, because of the big price. Moreover, the solutions proposed by the market outline a way of constant and continuous improvement and often the introduction of technology innovations makes quickly obsolete the previous solutions. Within a scenario so quickly changeable it seems good to study variable solutions at low cost, operational and effective immediately, although not definitive findings can help to overcome some problems still not completely resolved.
The approach developed and proposed in this paper, that the author liked to call as "topographical", introduces a innovative procedure as regards the classical techniques of city modeling, proposing a return to the use of surveying instruments traditional.
The measures of directions and distances, as well as making surveying operations rapid, redundant, and thus verifiable about results, make accessible 3D survey in urban areas to a greater number of users operators, proposing the integration of techniques of tested efficacy and of sensors widely distributed.
The study included, in the first part, the creation and deployment of testing platform for survey, equipped with a laser scanning phase measurement and a set of high precision topographic prisms. The platform is equipped with the housing for the laser scanner and for prisms in position and relative attitude constants, in order to permit, after calibration, the calculation of "reverse" position and attitude of the laser-scanner from the position of 3 prisms at least.
The combined use of a mobile platform and of a mobile tool prepared to welcome it to the super elevated position, can lead productive sessions surveying in urban environments, in stop-and-go modality, in order to get directly in the countryside a colored point cloud model.
The result can be carried out, "following" the vehicle within the city with a loose structure of topographic support, that is a simple polygon, or alternating topographic information with those from laser scanning for the union to mixed topographic-geometric constraint.
The platform is also designed for use in combination or in option to the prisms and the total station, GNSS sensors for orientation of the data set from the laser scanner, which can also be georeferenced.
The second part dealt with the issue of the use of cameras accompanied by wide-angle lenses (fisheye) in the generation of textures applied to geometric three-dimensional models.
The appearance of the coloration of the point clouds or surface-models is of great interest today because of increasing need to make a quick representation of detail and large-scale.
The interest in this technique also covers aspects of monitoring and control, from the urban scale and suburban to the one of detail for the deformations and crackings of continue faces.
It is investigated the possibility of realizing an hardware-software tool for internal calibration and orientation of rooms with automatic external optical short, to be performed for each session of surveying. In particular, we reported the first results on calibration of fisheye lenses by means of 3D patterns survey in the laboratory and then in sessions in the countryside.
This approach provides the refinement of perspective model to make it faithful to the behavior of optical lens used: they are made a comparison between different algorithms calibration and survey results of reprojection of images undistorted on models of clouds of point. The result can be achieved writing a piece of software for the piloting through the engines of laser-scanner sensors, lasers surcharges of cameras themselves, and for the treatment of certain data output of the laser itself.
The operating procedure for the acquisition and registration of the scans, developed in the thesis, it has been proved fast and efficient, but the e mobile equipment used is made in prototype form, which makes requires the presence of two operators to carry out operations of surveying and laser total station. It would be possible to facilitate and speed up the operations in the countryside giving the platform of "topographic prism active 360° " so there it would be no need for an operator assigned to the platform and the total station could "follow" automatically the target driven by remote location.
The potential of the platform to extend the scope with extra- the use of GNSS sensors for the alignment with procedures that reduce further manual detection. The alignment procedure outlined will be translated into a script and then engineered into a software that makes it less laborious phase data processing, providing and automatically align point clouds - without the operator having to obtain the matrices rototranslation - providing only the coordinates of the target detected in the country.
The results are satisfactory, and cost / km, as estimated on other case studies, this technique poses in a privileged position for use in works of small and medium size, minimizing the use media and allowing a good control results. It 'obvious that similar detection mode is a solution of transition and that in the near future to increase the number of GNSS satellites and accuracy of the INS will make this approach more convenient. It 'also denied that such an approach allows state of the art of cover dimensional requirements of knowledge of our urban heritage otherwise does not guarantee levels of cost and efficiency of other technological approaches.
With regard to the techniques of acquisition of RGB data, the results obtained using the 3D patterns are comparable with those obtained with classic method, though slightly different from the results obtained with self-calibration procedures. The use of a 3D pattern can however be easily adjusted and standardized in order to automate tasks recognition of the characteristic features of the pattern, both in point-cloud that photographic image.
The reprojection errors are likely to produce a color model with measurable residual errors pixel-point around 2 cm. Furthermore, the projection of the panorama creation process makes the technique expeditious and comprehensive in terms of describing reality.

# SOIL-STRUCTURE INTERACTION UNDER IMPULSIVE LOADING: INTERNAL EXPLOSIONS IN EMBEDDED PIPES

**Pamela Bonalumi**

Due to different accidental or intentional events related to important structures all over the world, explosive loads have received considerable attention in recent years and a renewed interest has been paid on design and construction of public buildings capable of providing life safety in face of explosions. While several guidelines have been provided, especially in the USA, to protect civil buildings under explosions, recommendations on underground facilities still lack. Thus, there is an urgent need to develop a practical and reliable methodology for the explosion damage assessment of underground structures, such as tunnels, capable of conveniently considering the soil-structure interaction.
In the framework of the European project ACCIDENT, focused on tunnel safety under exceptional loads, the work here presented aims at investigating the behaviour of a full-scale embedded pipe under the detonation of a high-energy solid explosive located within the structure.
Since explosions are quite complex phenomena, different specific objectives have been pursued. First of all, because of the lack of experimental results concerning the detonation of small charges made of solid high explosives, especially within pipes, a series of blast tests was performed on an open-ended steel pipe to investigate the repeatability of the blast load generated by such charges, which can be particularly affected by local effects, such as booster location, internal detonation process and charge positioning. Among all different high-energy explosives, dynamite ERGODYN 35E was adopted for the blast tests, because of its capability of fulfilling both physical properties and security issues requirements. To assure a good compromise between theoretically symmetric wave propagation and handiness of the explosive case, charges were packaged in cylindrical cardboard cases and hanged up in the middle of the tube central cross section, also to avoid contact problem between the structure and the explosive. Different charge weights (3, 6, 12, 24 g) were investigated with the aim of maintaining the tube in the elastic regime and several tests were performed for each charge weight, in order to assure a proper statistical sample (12 tests for 3 and 24 g charges and 6 tests for 6 g and 12 g charges). The steel tube is 1 m long and 10 mm thick, with an outer diameter of 0.61 m. It was properly instrumented with 5 ICP® pressure transducers, screwed in the thickness of the tube, to record the reflected pressure history at the inner surface of the pipe; 1 ICP® incident pressure transducers, located in the structure end section, to obtain the pressure values of the blast front in the centre of the tube and 1 uni-axial accelerometer, located on the top of the tube central section, to measure the radial acceleration of the section where the explosion occurs.

1. Blast tests on an open-ended steel tube

Then, a series of blast tests was carried out on a full-scale concrete pipe embedded in soft soil, by detonating different charge weights within the structure, to investigate the response of the soil-structure system both in the elastic regime, in order to collect statistically valid results thanks to the repeatability of the initial condition, and when damage is caused on the structure by the blast waves.
The blast tests consisted of three main stages. The first step was focused on the detonation of low entity charges (10 g and 12 g) within the pipe, to maintain the concrete in the elastic regime in order to avoid irreversible damages to the structure and to provide the proper repeatability. The second stage concerned the detonation of 12 g charges to investigate the possible influence of soil properties variations caused by the new digging and refilling operations. Finally, the third step regarded larger quantities of explosive (120 g and 1200 g) to produce a local damage to the structure in order to investigate the global soil-structure system behaviour in such conditions. Adopting such large charge weight, the destructive nature of the blast phenomena allows performing just one test for charge. A total number of 33 blast tests were performed.
The structure under investigation is a concrete pipe 26 m long and 85 mm thick, with an inner diameter of 1.0 m, connected at each end side to a shaft. The pipe is made of different precast segments with a length of about 1 m each and is embedded in soft soil at a depth of about 2.30 m. The concrete tube was properly instrumented in 5 different sections along the tube with: 7 ICP® reflected pressure transducers, 1 ICP® incident pressure transducer, 8 uni-axial radial and longitudinal accelerometers and 10 hoop strain gauges. Moreover, 4 biaxial accelerometers were placed within the surrounding soil at different distances and depths from the pipe central section where the explosion occurs.


2. Blast tests set-up on the embedded concrete pipe

Finally, numerical simulations of the performed blast tests were carried out to check the feasibility of simplified models on the basis of the experimental data.
The CFD finite element code Europlexus, specifically developed for fast transient dynamic phenomena by the Commissariat à l'Energie Atomique of Saclay and the Joint Research Centre of Ispra, was adopted for all numerical calculations to perform fully coupled analyses capable of taking into account both fluid-structure and soil-structure interaction.
Due to the lack of data related to internal detonation in embedded pipes, the present work focused mainly on the experimental approach, to collect a series of data that can represent a good benchmark to evaluate the response of a soil-structure system under blast loads. The numerical approach was mainly devoted to validate preliminary simplified models and to understand the main features that can affect the phenomena through parametric analysis.

# THE GEOPHYSICAL INVERSION OF GEODETIC DATA

**Silvia Faini**

This paper addresses the problem of geodetic inversion, describing the procedures for estimating the slip distribution from the surface data: we applied the Okada's model to the Pollino fault.
This model allows computing the superficial deformation given the velocity on the fault plane and vice-versa. The observation equation is $d = Gm + \varepsilon$, where d is the vector of superficial movement data on the points of measure, m it is the vector that contains the velocity on every patch of the fault plane, G is the Green matrix that contains the movement due to a unitary velocity on any patch, calculated through the direct model of Okada on any point of observation. $\varepsilon$ is the error vector, that is assumed to be normally distributed, with zero mean and covariance matrix $\Sigma_d$.
The main purpose of this thesis is to introduce new methods of inversion and analyze the differences in order to see the one with the best characteristics.
Initially, the model used for the inversion is the same used for simulating the surface data.
In this case we test the resistance of the different inversion methods to the noise in the data. Then, we investigated the possibility of identifying the proper model while inverting the data. So we make a comparison between the methods by varying the models (at a given noise level in the data). The inversion is taken over with four different models: only one of them is coherent with surface data set.
To define the models to be used in the simulation, a variability analysis of the Okada model was performed. The aim of this analysis was to define the most sensitive parameters in the model, i.e. those giving the highest variability in the surface velocity pattern.
This analysis brought us to consider as important the East, North and Rake parameters. However, because of the fact that this fault has an almost superficial side, the East and Nord parameter can be considered sufficiently known, while a small variation of the parameter of Dip is introduced, because it allows to better distinguish the horizontal components from the vertical one.
The first method we analyzed is the simple least square method. This is undoubtedly the simplest method although it gives unstable solutions, that is velocity fault patterns with strong patch variations which are not physically acceptable.
Because of this instability, a smoothing parameter $\beta$ is introduced, which determines the relative weight placed on fitting the data versus smoothing the fault velocity filed. This is a classical regularized least squares method.
In this approach, the velocity on the of fault plane is given by:

$$m^{est} = < m > + [G^t W_e G + \beta W_m]^{-1} G^t W_e (d - G < m >)$$

where $< m >$ is the guess solution, $W_e$ is the observations weights matrix, $W_m$ is the gradients matrix and $\beta$ is the regularization factor, which represents the weight given to the regularizing condition on the fault velocity gradients.
Naturally, in this approach the problem of the choice of a proper $\beta$ occurs. This parameter must be selected to balance the two conditions, i.e. to maintain a reasonable surface data misfit and a feasible smooth velocity filed over the fault plane.
We first considered a fixed $\beta$ value, select on the basis of geophysical hypothesis, which however gives poor results. So a statistic index is introduced to choose the optimal value of this parameter.
Varying $\beta$, the least squares smoothed solution is computed, and its variance is used to calculate the statistic index $\chi^{2*}$, $\chi^{2*} = (\sigma_0^2)^{est} / \sigma_0^2$, where $(\sigma_0^2)^{est}$ is the estimated variance and $\sigma_0^2$ is the a priori data variance.
Then we compare the $\chi^{2*}$ values of with the corresponding theoretical values of $\chi^2$ to a level of significance equal to 5%.
With a Fischer's test we also verified that all the subsequent $\chi^{2*}$ values, obtained by further increasing the $\beta$ value, are statistically equivalent to the first significant one. By selecting the solution given by this first $\chi^{2*}$ we make a conservative choice, for we take the smoothest solution given the same misfit on the surface.
Also, the same regularization condition is introduced following a Bayesian theoretical framework, to analyze the reliability of the methods to the noise in the data.
In the Bayesian method, the equation of observation (*likelihood*) $d^{est} = G m + \varepsilon$, for which we assume that the error distribution is $\varepsilon \sim N(0, \sigma^2 Q_d^{est\,est}_d)$, is translated by its *p.d.f* $p(d^{est} \mid m, \sigma^2)$ which is assumed to be a normal distribution, with Gm mean and covariance matrix $Q_d^{est\,est}_d$, where $d^{est}$ means estimated d.
The prior information (*prior*) is based on gradient regularization. The stocastic model for the prior information is $D m = \delta$ , where D is the gradient matrix, $\delta \sim N(0, \alpha^2 I)$ and $\alpha^2$ is a scale factor to be estimated.
To determine the best value for the parameter $\alpha^2$ we refer to a criterion called ABIC (**Akaike's Bayesian Information Criterion**) suggested by Akaike on the base of the principle of maximization of the entropy.
From the first comparison we can say that the inversion with a fixed $\beta$ is not an optimal inversion, even if the method leads to results which can be compared with the results (misfit) of the other methods.
The optimal $\beta$ inversion method sometimes does not lead to any result since it does not allow to invert the Okada model.
In the case of the GPS points, too few and badly distributed in comparison to the position of the fault, it does not allow to obtain a meaningful solution.
On the other end, the Bayesian method always leads to an inversion, but, in the case in which the optimal $\beta$ method also leads to a solution, the two methods are comparable.
On the other hand, if the optimal $\beta$ method fails, the Bayesian method does not give reliable estimates: it gives results similar to those obtained using the fixed $\beta$ method.
The combination of the Bayesian and the optimal $\beta$ methods allows to prove if the inversion with a data set is feasible and, in this case, to make an optimal inversion with the Bayesian method.
The inversion on the SAR points is optimal on the patches which are closer to the surface, thanks to the high number of data and to the good position of the points over the fault area.
In other words, the inversion of the vertical component, because of the used method and of the type of fault we considered, gives us best results in comparison to those related to the horizontal components.
The second comparison, the one we made changing the model to verify if there is the possibility to reveal, during the inversion process, the suitability of the model we chose, allows to observe that all the methods of inversion recognize the correct model. Furthermore, the Bayesian method always gives an indicator of surface misfit which is smaller in comparison to the misfit obtained with the other methods. Moreover, the optimal $\beta$ inversion method gives a better discrimination than all the other methods between the correct model and the other adopted models.

# STATISTICAL INFERENCE OF GEODETIC OBSERVATION IN GEOPHYSICAL INVERSION MODELING

**Künzle Annamaria**

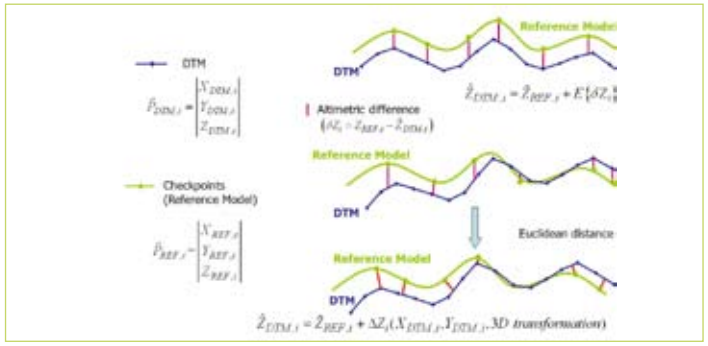
Geodetic monitoring in seismic areas is a set of procedures for data analysis, whose main purpose is to determine whether a given surface deformation is consistent with a certain, predefined, geophysical fault model. Geodetic measurements are acquired using different techniques such as SAR and GPS.
The product of the SAR technology consists of maps, called interferograms, obtained through the comparison of two satellite images captured with the same viewing angle at different times, through which it is possible to detect the ground deformation.
A monitoring network of GPS measures the daily geometric positions of a large number of points on Earth's surface and enables to describe the deformation over a time span even if the deformation is slow compared to the time of detection.
As known the accuracy of GPS measurements is higher for the horizontal component.
In the analysis carried out, GPS measurements are referred only to the horizontal components, leaving to SAR measurements the detection of the vertical component of deformation.
The Okada model and its inversion has been used to determine the surface deformation originated by a displacement on a fault plane in depth, and vice versa.
The direct model uses the Green's matrices that depend on the following parameters: position of the fault plane (E, N, Z), size of the fault plane (Length and Width), strike angle (azimuth), dip angle (immersion) and rake angle (distortion).
For the inversion we chose to use a smoothed least-squares method in order to take into account the real geometry of the problem and avoid the presence of gaps between the gradients of the individual patches of the fault.
The model for the analysis was the Pollino fault. According to the Database of Individual Seismogenetic Sources, the Castrovillari fault in the Pollino area is assumed purely normal. It is discretized into 12 patches, each with a constant velocity value.
For the measuring points on the surface we have considered an 11 x 11 grid of points uniformly distributed at a distance of 3 km for both SAR and GPS, this in order to define the properties of the model and inversion methods in an optimistic and ideal case. The points have been also considered as distributed according to the real surveyed GPS and SAR positions.
At the beginning a variability analysis of the Okada model has been carried out. The purpose of this analysis is to identify the parameters whose variation affects mainly the variability of the estimated values of strain on the fault plane, in order to build different models of fault for further analysis. Given a structure of strain on the fault plane, it has been evaluated the response of the model in respect to parameter variations. From this analysis the parameters of North and East position of the fault and rake angle appear to give the strongest variability.
Considering the position of the emerging position of the fault a sufficiently known parameter for the purposes of our analysis, the rake and the dip angles has been chosen as variable parameters. This latter, although not particularly important into the analysis, changes substantially the projection of the strain from the fault plane to the surface.
Four different models of fault has been built: two models of normal extensive faults with different values of immersion, and two models of extensive faults with transcurrent component one right and one left. A group of inferential procedures designed to discriminate the geophysical model that best interprets the data observed on the surface on a statistical basis have been constructed.
In order to validate the methods for choosing the fault model that interprets at best the data on the surface the following procedure was carried out: from the strain on the fault plane were generated by simulation the data of surface deformation using a model of fault chosen from the four described above. Noise has been added to the deformation on the surface obtained. Assuming the data generated as observed data and that the model that describes the fault as unknown, we developed a series of test procedures to determine if one of them has a better fit to identify the model of the fault plane used to generate the starting data.
The knowledge of the fault model that generated the data on the surface, data that we assumed as observed, enables to properly evaluate the properties of these tests at different noises and for data observed in different positions.
These procedures can be divided into two classes: a direct comparison, performed component by component and a cross comparison, performed integrating the two different measurement types SAR and GPS.
For the direct comparison, two parameters of the Okada model, the dip and the rake, are considered as variables with the aim of introduce a level of uncertainty on the model, giving a more realistic understanding of the reality of the problem.
For the cross comparison, it is possible to consider the presence of two different types of independent observations of surface deformation as these data are acquired not simultaneously, with different instruments and in different measuring positions. It was decided to use the vertical SAR data for the geodetic inversion and lead the comparison on the horizontal GPS data.
Some of the statistical tests used to determine which model best describes the simulated data on the surface, require the generation of a covariance matrix of the model. Depending on the type of comparison, direct or cross, a different procedure for the calculation of this matrix has been adopted.
The calculation of the covariance matrix of the model on the surface was carried out numerically for the direct comparison, since the matrix G depends non-linearly on the parameters that characterize it and it is therefore difficult to apply the variance propagation law. A number of surface deformation data has been generated and the covariance was calculated at a certain step "p" as the average on the number of the simulations of products of the deviations from the average.
For the cross comparison, the inversion of the Okada model, carried by the smoothed least square method, gives the covariance matrix of the strain on the fault plane. Considering the functional relationship and the Green matrix as a constant, it is therefore possible, to apply the variance propagation law to calculate analytically the covariance matrix of the model.
To achieve the characteristics of definite positivity and diagonal dominance of the covariance matrices, in both cases it was decided to calculate the empirical covariance and then to interpolate it using an exponential or a normal model function. The choice between these two models was carried out using the AIC criterion.
To perform the comparisons four statistical tests have been used: a classic test, a classic test with a covariance matrix model, a Bayesian test and a distribution free test.
Each test has been executed on the grid and on the measurement points, at different classes of noise.
The tests never come into significance. For this reason it was decided to sort the $\chi^2$ values and to consider as the right model that interprets the data the one giving the smallest $\chi^2$ value.
Both the classical tests identify the correct model in each simulation as the one that actually generated the data, although when the noise is high the difference between the models appears to be less discriminating.
When the noise is higher the Bayesian test gives the best result because it discriminates more clearly the right model showing a more pronounced minimum than the other tests.
The Friedman distribution free test is very similar to the classic test in most cases, although there are some simulation in which this test fails even with a small level of noise.
It is shown the presence of a weaker horizontal coordinate according to the model used for the simulation; this seems to depend on the rake direction of the fault and from its general structure.

# 3-D ADJUSTMENT OF A DTM/DSM WITHOUT A PRIORI HOMOLOGOUS POINTS

**Xuefei Liu**

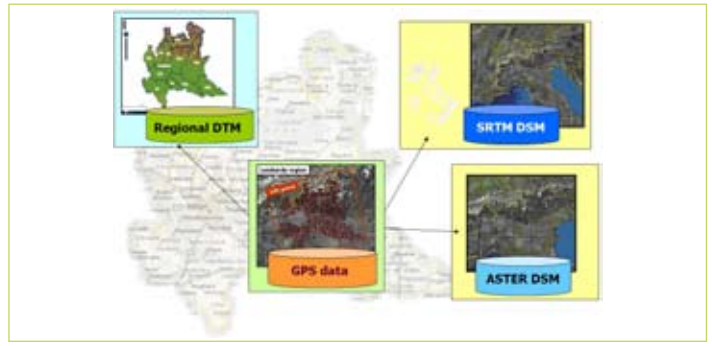
This dissertation has proposed a method for detecting and adjusting 3-D errors in georeferencing of a digital terrain model (DTM)/digital surface model (DSM).

Accuracy check of a DTM/DSM product is usually carried out with the help of a reference elevation data, which can be either another DTM/DSM or a set of irregularly distributed 3-D points. The reference elevation data should have not participated in the generation of the DTM/DSM; moreover, they are generally characterized by an accuracy of at least one order of magnitude higher than the DTM/DSM to be examined. Models subject to 3-D adjustment need to be transformed into the same geodetic datum before the calibration process. If there is only a simple translation between the two models, the classic two-and-a-half-dimensional (2.5-D) calibration, which considers merely the average altimetric distance between the models, should be enough. Unfortunately this is not always the case, on the contrary, error in elevation data is widely recognized to comprise mainly two components, the horizontal, often referred as positional accuracy, and the vertical component or accuracy of the attribute. However, positional and attribute accuracy generally cannot be separated; the error may be due to an incorrect elevation value at the correct location, or a correct elevation for an incorrect location or some combination of these. In other words, georeferencing errors should be modeled in 3-D manners, i.e. both rotation and translation should be considered between the two models, a 3-D spatial transformation should be introduced to describe the georeferential difference between the target DTM/DSM and the reference data.




1. From the traditional 2.5-D to 3-D calibration

The adjustment process is realized via a 3-D comparison with reference altimetric models of better accuracy, by a matching process based on a 3-D geospatial transformation without scale factor correction. The matching process of the two altimetric models is based on the estimation of the six parameters of a geospatial transformation between two 3D surfaces in a local Cartesian coordinate system, minimizing the Euclidean distances between the surfaces by least squares method; this procedure does not require the a priori availability of homologous points.
By examining the six parameters, we have clues on the potentially existing systematic errors, which can be either in translation(s) along three axes or rotation(s) around the three axes, or a combination of the two.
As important as the least squares estimation procedure itself is the analysis of the statistical significance of the resultant estimation.
This analysis permits to assess whether the parameters are significantly different from 0, with a confidence level determined in advance.




2. A schema of the experiment comparisons

In other words, with the help of the statistical significance tests, we judge (at a certain set-up confidence level) if there exist a significant rototranslation between the two models.
Moreover test of significance in each single parameter reveals the potential significant rototranslation is due to translation(s) and/or rotation(s) along certain direction. Null hypotheses of these tests are to assume the transformation parameter vector u (or the single parameter) equals to zero, i.e., to assume that there exists no rototranslational transformation between the REF model and the target DTM/DSM (or no translation or rototation along/around the certain axis in the case of single parameter tests).
If the DTM/DSM accuracy is unknown in advance, a Fisher's test is applied to the whole parameter vector while a Student's t test to each single one of translation parameters and rotation parameters of the transformation; if, instead, the DTM/DSM accuracy is known a priori, a chi-square test is used to test the parameter vector's significance, while a Z-test is used to test the significance of each single transformation parameter.
The accuracy check of a DTM/DSM can be carried out in two steps: A parameters estimation process is employed to assess the proper georeferencing of the target DTM/DSM by certain method; with the result of parameters estimation, one can correct the eventual errors shown in the target DTM/DSM, the output of such a process can be a new set of calibrated grid, with the parameters applied.

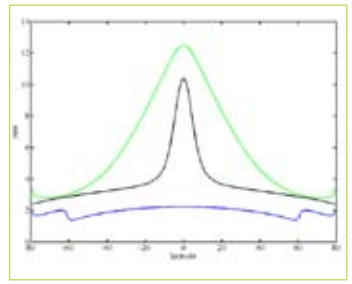
The methodology has been implemented in an independently developed package called REF2DTM [(from) REFerence data to target DTM/ (DSM)], composed by a series of routines and procedures written in MATLAB® environment, its codes are open.

A series of DTMs/DSMs generated by diverse data sources in Lombardy, northern Italy have been examined: small scale DSMs from SRTM data (grid spacing: 90 m, accuracy: 16 m) and ASTER data (grid spacing: 30 m, accuracy: 20 m), medium scale regional DTMs (grid spacing: 20 m, accuracy 5 m) and large scale local DTM derived from LiDAR survey (grid spacing: 2 m, accuracy: 20 cm); on the other hand, direct GPS measurements with an accuracy of the order of few centimeters have been used as reference model to adjust the above-mentioned DTMs/DSMs.
Results of these comparisons suggest that, with respect to the GPS data, local LiDAR DTM, the regional DTM and ASTER DSM show significant systematic errors in translation and in rotation, both in 3-D term; SRTM DSM, instead, doesn't show a significant error in its georeferencing compared to GPS data. Before the further application of the first cases a complete three-dimensional adjustment is indispensable to remove all 3-D systematic errors.

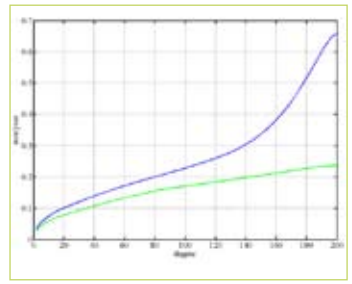
# ERROR BUDGET OF FUTURE SATELLITE MISSIONS TO MONITOR GRAVITY FIELD TIME VARIATIONS

**Lisa Pertusini**

Satellite gravity missions provide an ideal way to monitor mass distribution and its variations on a global scale, because they are directly linked to gravitational orbit disturbances.
Currently three space missions are flying: CHAMP , GRACE and GOCE, each one with its own strong points and drawbacks.
All these missions are based on the principle that the tracking of any satellite represents a measurement of the gravity field in a series of points along its orbit; furthermore each satellite carries on-board accelerometers which make possible to detect (and so remove) the effects due to non gravitational forces.
The measurement of the distance between a couple of satellites flying on the same orbit (GRACE principle) or the direct observations of gravity gradients (GOCE principle) can significantly improve the accuracy and the resolution of the estimated gravity field model.
After the launch of GOCE the interest of the scientific community has gone to the study of a future satellite mission which enables the recovery of time variations of the gravity field at high resolutions (up to a maximum harmonic degree of 200 or higher) over a long period of time, at least 5 to 10 years.
A number of studies have been carried on in recent years, with the aim of choosing which satellite mission design will be the most suitable as a GOCE/GRACE follow-on.
Very complex satellite formations have been investigated and the first results say that they could actually estimate time variations of the gravity field with high accuracy and resolution, to make satellite gravity missions really able to monitor a large number of geophysical phenomena on a global scale.
However these configurations are very expensive and need for further investigations on their feasibility.
Due to financial and programmatic constraints a simpler and already well known flight configuration seems to be a reasonable candidate for the next Earth Explorer mission by ESA. It consists in a Satellite to Satellite Tracking mission in the low-low mode (SST-ll), which is the same mission configuration as GRACE, but carrying improved instrumentations.
In particular, in the ESA study "Laser Doppler Interferometry (LDI) mission for determination of the Earth's gravity field" made by Alenia and other Universities and Research centres in 2005, the use of a heterodyne laser interferometer for the high-resolution measurement of the displacement between two low co-orbiting satellites is investigated.
Furthermore, the two satellites carry very precise accelerometers, for the accurate measurement of non gravitational forces.
An improvement in the results by only doubling the costs and the computational burden can be achieved by launching not only a single pair of satellites on the same orbit (like GRACE), but two couples of co-orbiting satellites on complementary inclination orbits.
In the present work a semi-analytical model has been developed in order to express the geopotential measurement error as a function of the noise power spectrum of the accelerometers and the interferometer on board an LDI mission for a SST-ll configuration.
In the above mentioned study of Alenia a very approximate analytical method was used to assess the optimal main mission parameters. Therefore the results obtained by the present procedure are compared with the old estimates, in order to assess their level of approximation and check if the proposed mission parameters are still optimal by applying the new method.
The present method is based on Fourier analysis to easily solve Hill's equations and to a least-squares mapping from Fourier to spherical harmonic coefficients which are commonly used to represent the gravity field on a global scale.



**1. Comparison between the cumulative geoid undulation error up to degree 200, excluding polar areas: analytical method in black, semi-analytical method in green, semi-analytical method for two couples of satellites in blue.**



**2. Trend estimation error of the geoid variations considering a 6-year mission for a single couple of satellites (in blue) and a twin couple of satellites (in green).**

An important result is that the proposed method, although requiring the solution of a least-squares problem with tens of thousands unknown coefficients, is easily computable with a simple personal computer, thus allowing the analysis of many different mission profiles and the selection of the optimal one. This fast solution is possible thanks to the block diagonal structure of the least squares normal matrix.
As regards the comparison of the present results with the previous method ones, it is proved that the closed form expressions derived in the latter can be seen as an approximation of the semi-analytical method under some simplification hypothesis.
The error budget of the LDI mission has been recomputed with the semi-analytical method showing that the approximation used in 2005 do not significantly affect the estimated maximum resolution and accuracy.
The main impact of the previous approximation was in the evaluation of the polar gaps effect (namely in the accuracy of low order coefficients) which was heavily underestimated.
On the other hand, the previous mission parameters (and in particular the inter-satellite distance, which is the most important one) have been re-evaluated and optimized according to the proposed semi-analytical method.
The main achievement of this analysis is that the inter-satellite distance has to be increased from 10 km to 30 km. This leads to an accuracy of 4.1 mm in the estimation of the static geoid undulation with one year of data and an accuracy under 0.25 mm/year in the trend determination of the geoid variations due to secular geophysical phenomena (a mission length of 6 years has been considered).
Furthermore, a slightly more complicated mission profile has been considered to improve the error distribution especially in the equatorial area where the data density is lower. Instead of launching a single couple of satellites at 350 km altitude and with an orbit inclination of 83.13°, an additional couple of satellites could be launched, simultaneously flying on a orbit with the same altitude but with an inclination of 60°, which has been selected after evaluating different possibilities. In this case we can get an accuracy of 2 mm in the estimation of the static geoid undulation and an accuracy of about 0.5 mm/year in the trend determination of the geoid variations.
The final conclusion that can be drawn from this thesis is that SST missions with on board a laser Doppler interferometer and accurate accelerometers have an error budget which seems to allow the estimation of gravity field time variations at very high resolution and accuracy.
This in turn will allow to detect and monitor geophysical phenomena that probably have never been observed before from space and therefore never studied at a global scale.

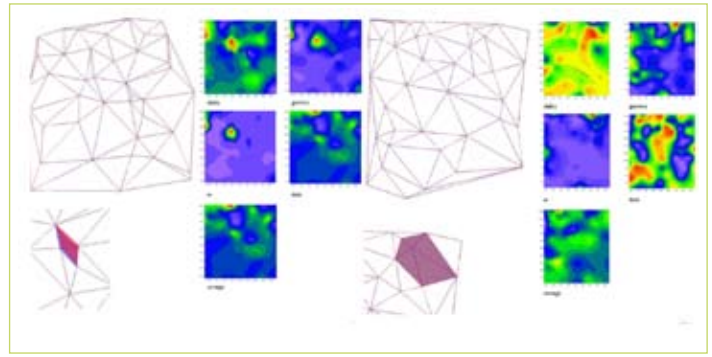
# STUDY ON DTP SCANNER DEFORMATION

**Micol Pillon**

The systematic scanning of photographic archives, old books and historical maps is an established practice in museums, libraries or archives.
The main aim of this operation is to preserving the information contained in these materials that can be damaged by the years go by and by a not always appropriate care.
At the same time, the digitization has made available a huge amount of data, often managed by computerized database, in which the image at different resolutions can be used for many surveys and studies, including studies can certainly enumerate cartography and photogrammetry.
To use a digital image, also useful to the science of Geomatics, it is necessary to establish a relationship between the location of the image pixel and the coordinate system x, y of the raster plan. This operation should fix a reference system that joins the pixel's coordinates to real coordinates.
This correspondence in the digital image is clearly identified by the array of pixels and it is the same image acquisition system which then can transform the radiometric value of pixels in a given position x, y. The acquisition unit used must therefore provide the digital image so that, for each pixel, can be associated with the pair of coordinates. Each single pair of coordinates should be already correct errors that would cause a deterioration of precision in the analysis of the scanned image.
The analysis of errors made by low-cost flatbed scanners (DTP Scanner. DeskTop Publishing Scanners) is the purpose of this study.
DTP scanners are commonly used as units of major achievement in museums, libraries and archives for one simple reason: their low cost and easy to use.
Currently, digital capture devices to high precision, such as, for example, photogrammetric scanners or densitometers, continue to have a cost not always affordable by all institutions and would be too expensive to order, to those who already have such equipment, a campaign digitization.
For this reason, they often opt for the use of low-cost flatbed scanners that currently can achieve higher and comparable resolution to those that can be obtained with high precision instruments.
The low-cost flatbed scanners, however, unlike the instruments more accurately, do not represent instrumental errors, let alone allow you to apply procedures for their elimination.
So, how can we operate to find a way to eliminate this errors?
Is it possible?
In order to evaluate the errors in these instruments, it has been put in place three different scanning procedures, procedures that are designed with the aim to isolate the errors made by the sensor and errors introduced by the carriage that allows to the sensor to runs from top to bottom.
Assuming that all images used for this test have a maximum size of 20x20 cm, three procedures are introduced. The procedure 01 can identify the error made by the sensor, the direction that will be indicate as the x direction. The scans in this procedure have been achieved by keeping the scan document always placed in the same position on the glass. The procedures 02 evaluates instead the y component of the error, introduced by the movement of the sensor down. The image is thus scanned by changing its position on the floor and moving along the y axis.
In the procedure 03 the images are scanned in the correct direction first and then with a scan rotated 90 degrees so that they can evaluate the differences between the two scan lines.
If such systematic errors in any of the images appears into the pair of scanning , it should be therefore possible to correct the systematic errors by using the scanned image in the opposite direction.

To estimate the presence of errors, two different sets of images were chosen. First of all a grid pattern was used to verify the geometrical errors in three different DTP scanner. The data analysis shows how there is a trend into the y direction of the image: at the end of the patter

1. Scans procedures: procedure 01, procedure 02, procedure 03



2. Example of strain analysis elaboration on different images

image the error increase in every single image. However the error in the x direction is not stable and it's not possible to recognize the presence of a systematism.
Into this part of the analysis the radiometric error was not considered. To study the possible deformation into the pixel signal it was decide to evaluate the correlation coefficient between each single area of the image.
To study the coefficient c the software correlation.exe was implemented to stimate the correlation into a template area of the images and along a particular movement grid.
The local value was also verified by the use of ImageJ, a open source software of image processing, implemented by the medical community to analyze image stacks. In this case the correlation is no more a local data but the value is calculate for each single pixel and it's possible to verify the distribution of the parameter.
All data obtained by the grid pattern image are really congruent. Two images are not identical, even if the scanning position is always the same on the plane.
The second set of images that we considered was made by a series of photogrammetric images on the Venice city.
In this set the procedure of analysis to verify a possible geometrical errors on images was made by the use of the tensor analysis. In particular the image acquired with the procedure n°03 were considered as a body in two different state: a quiet and a stressed state.
The analysis shows how the strain is evident into a couple of images, but it also shows how it's not possible to establish a relation between an instruments and the presence of systematic errors.

At the end this works made clear that it's not possible to find constant errors into this instruments. Their electronics and mechanisms are too instable to describe the best way to control or eliminate all errors introduced by a DTP scanner in a single scan. Use these instruments to realized the classical cartographical or photogrammetric product as maps or DTM is not possible, even if this instruments are very useful to digitalize images and documents to preserve the information given by every kind of documents.

# STATISTICAL ANALYSIS OF THE PHAISTOS DISK

**Ettore Scorsetti**

The Phaistos Disk is an archaeological finding brought to light in the town of Phaistos, on the island of Crete, under the wall of a minon palace of the hellenistic period, during a scientific expedition guided by the italian archaeologist Luigi Pernier, in July 1908.
It is a terracotta, not perfectly round, disk, with a diameter ranging between 158 mm and 166 mm and a thickness ranging between 16 mm and 21 mm. These elements suggest that it was obtained by compression from an excellent quality potter's earth.
The Disk is strewn with undeciphered symbolic forms impressed with a stencil plate on soft clay, forming spirals on both faces. Stratigraphy traces back its origin to 1700 b. C.
Many famous scholars undertook its interpretation in the course of years, proposing more or less logical and coherent, but fascinating and paradoxical, solutions.
In the last century, in fact, the Phaistos Disk has raised a host of theories and stories, just like a magical object containing them all, and enjoying itself, as if it was endowed with a soul of its own, to tell continuously different tales.
For this reason - and because of the exiguousness of the piece - no unique translation of its content is possible, nor can any proposed, even fanciful, translation be excluded.
We conventionally defined A and B the two faces of the Disk. Face A contains 31 groups of signs, for a total of 123 signs; face B contains, in its turn, 30 groups of signs, for a total of 119 signs. The number of legible signs on the Disk amounts to 45. The starting point for its reading is shown by a line bordered by 5 small points on the most external part both of face A and B.
The characters of the Phaistos Disk were impressed by means of 45 prick-punches, and probably constitute the first historical case of an inscription realized by movable types, which were unfortunately lost. This very property is a singular point of the Phaistos Disk.
The different "sections" of the "text" are neatly separated and distinct, the ones from the others, by means of a system of vertical small bars which, together with the spiral line, enclose each semantic unity inside a strongly limited space restraining the spanning of each word.
The analysis of characters does not allow to attribute them to any well-known writing system.

The supporters of the thesis that it contains a definite writing system had to admit - beginning from Ventris and Chadwick, in their *Documents in Mycenaean Greek* - that it must probably be an aegean, and in any case a syllabic, type of writing.
Nobody questioned, on the other hand, the fact that it is a form of writing. But nobody was able neither to decipher this obscure message coming from such a remote age, nor to recognize the code of this communication form.
Other elements, moreover, induce to question the fact that it is a form of language.
One could suppose a syllabic type of language, but many sections contain sequences of 6 or even 7 signs, which would correspond to excessively long words.
It must be stressed that, according to the internal analysis of the signs of each section, it appears quite strange that the sign of "warrior with helmet" should onlyappear at the beginning of each sequence on both sides of the disk; it is also quite strange that series of two repeated signs do exist, but never at the beginning of a sequence, and that there exist position variations of some signs sometimes rotated by 45°, and sometimes displaced without a specific rule.
The singularity of the semantic character of the different sequences of the Phaistos Disk, in conclusion, does not induce scholars to support the idea that it corresponds to a language. The singularity of the semantic character of the different sequences of the Phaistos Disk, in conclusion, does not induce scholars to support the idea that it corresponds to a language.
That is why other intepretative hypotheses were developed, the first one of which is that the Phaistos Disk is simply a calendar-diary journal conceived for young people, or perhaps for any kind of people, of that period; so that the intepretation and evaluation code should be quite different.
A quite striking fact is the number of sections into which each face of the Disk is subdivided: 31 one on face A, and 30 on face B. This peculiarity is too much evident to be ignored, and it cannot be ascribed to a simple coincidence.
Here the circular form of the piece is related to the solar circle and to its annual motion, and it appears to represent a picture of the sky, and therefore a kind of time computation in correspondence with astronomic and/or seasonal events.
This may be realized at first glance and approach;
the "text" analysis suggests then that the circle could express, either immediately or symbolically, geo-mathematical knowledges concerning the picture itself.
As far as signs are concerned, it may be observed that both faces begin with the same image, the "warrior with helmet": an evidence of the fact that war activities were of primary and fundamental importance for the community.
Other activities may be clearly identified, such as that of drawing the bow, sailing, making helmets and armours, leather tanning, using rasp, drill and hatchet and practicing agriculture, or even music.
Other signs are less easily identified, and on the very success of this identification shall depend the possibility of building a picture of the customs and culture of this people, which dedicated itself also to fishing, gymnastics and sheep-rearing, began fig growing and even established advanced relations between sexes, as the presence of female figures appears somehow to indicate.
There also exist other signs, whose meaning is unclear, and whose significance must still be identified. There also exist other signs, whose meaning is unclear, and whose significance must still be identified.
In spite of what has been written so far, however, the present work has developed the hypothesis that the signs traced on the two faces represent alphabetic characters, and that each group of them represents a single word; we developed therefore, by means of specific notations of discrete mathematics, a statistical analysis of the sequences of signs contained in the Disk.
The work presented here is organized as follows: a purely statistical data analysis has been developed, starting from general descriptive statistics, and facing first the analysis of the simple, and then of the double, statistical variables.
Plots have been built, case by case, of the symbol frequencies both globally and for each single face.
The dependence between different characters of each face of the Disk was evaluated (by analyzing first each one of them from inside to outside, and then backwards) by means of the Bonferroni coefficients, and a linear correlation analysis was performed by a suitable program allowing to draw the regression straight lines of the data.
We then went on with:
the best fitting tests on the statistical indexes provided by the previous analysis,
the classical independence Kolmogorov-Smirnov tests,
the Pearson normality tests,
the chi-square variance test,
the *t* test on each parameter of the straight lines,
the correlation coefficient test,
the study of the graphes aiming at visualizing the syllabic successions,
the Cluster Analysis aiming at visualizing the thematic frequencies in the two faces,
and, in conclusion, the study of the planes $2^k$ ANOVA.
The conclusion of the work included a confrontation with the archaeologists, philologists and linguists of the **Dipartimento di Diskipline Storiche "Ettore Lepore"** of the **Università degli Studi "Federico II"** of Naples, who recognized the value of the work, and gave significant comments.
Successive demonstrations provided the analyses both of the initial 24 verses of the first **Canto** of Dante's "**Inferno**" and of a front page of New York Times, aiming at controlling and comparing the behavior of an ancient and of a modern language - but comparisons lead quite far…

# DIGITAL MANTUA: TOOLS FOR THE VALORIZATION AND KNOWLEDGE OF CULTURAL AND ARCHITECTURAL HERITAGE THROUGH 3D DIGITIZATION

**Laura Taffurelli**

The present work aims to present an overview of major systems of representation and advanced applications to Cultural Heritage and bring the study of analytical and operational methods in the literature as the detection of the state of the art.
The thesis wants to highlight, through the proposal of some significant examples, the current issues and key aspects of three-dimensional modeling of real objects, the so-called inverse modeling. Comparing methods of survey with active and passive sensors in close-range application is highlighted as the integration between these is now a practice.
For decades, we talked about multi-scale and multi-technique integration in order to achieve more accuracy and completeness in describing the complexity of an object, especially a BC, but it is only a few years we are able to verify applications pushed to a first three-dimensional approach by research groups from various scientific fields and applications.
The use of two-dimensional representations continues to be indispensable in a summary of a project, (of restoration, architectural or industrial), however, three-dimensional acquisition and representation are no longer just a means but are becoming the order of the research work. The future seems to be oriented towards the establishment of computerized three-dimensional geo-referenced database where the integration of several methods with different resolution, accuracy, precision, cost and other issues helps to enrich the quality and verifiability of these.
The thesis will seek to bring progress and addresses of this field of studies and to highlight the critical, by describing the personal path followed. Taking the example of architectural and sculptural objects in the city of Mantua and Sabbioneta (Human Heritage since 2008) the work try to point out, moreover, an aspect that scientists working in the field are familiar with, but that is sometimes overlooked by government or by the same technical managers of restoration projects: the digital documentation, through appropriate technical and cognitive tools (verified or verifiable), allows the enhancement of cultural heritage, but also allows the dimensional and geometric documentation of the survey, as well as its conservative state at the relief time.
The project stems from the intention of collecting and managing relevant data of the city of Mantua and Sabbioneta acquired between 2006-2010 in the context of this PhD research and in the cooperation between La.Ri.Fo.Laboratory, Politecnico of Milan, *Soprintendenza dei Beni Storici Artistici ed Etnoantropologici per la Provincia di Mantova* and the City of Sabbioneta.
The acquisitions made in recent years have concerned important monuments and architecture representing the heritage of these two cities, together a UNESCO site since 2008. This material was produced both to support the conservation and restoration, both as a tool for historical and research evaluation, in order to understand better the evolution of architectural artifacts.
The organization of this data create a single index of information relating to reliefs and allows the usability of different kinds of users (historians and researchers, technical staff of the *Soprintendenza*, simple web users); it is proposed as a project to develop, according to the Management Plan of Unesco site of Mantova and Sabbioneta. For the transmission of their memory, digitization of Cultural Heritage needs the knowledge of their geometry, their shape and their relationship with the context in which they are inserted.
The digital reconstruction through models can take over an asset beyond time and space, beyond the physical boundaries and becomes an instrument of interaction.
Therefore, an applied approach describes the main methods for obtaining a relief and a three-dimensional representation through models, that are suitable for both container and content of information.


1. Html interface for navigation and consultation of Mantova Digitale Database 3D for the knowledge and valoritation of Cultural Heritage

2. Some architectures and sculptures of the cities of Mantova and Sabbioneta detected and modeled with different technologies


3. Comparison of various methods of survey and 3D modeling

# METHODOLOGY FOR THE RECONSTRUCTION OF THE WATER CIRCULATION IN THE MOUNTAIN AQUIFER: INTEGRATED APPROACH

**Silvia Terrana**

## Introduction

In the last few years, a progressive impoverishment of water resources has taken place in the mountain around the globe due to the increase of anthropogenic activity and changes in the precipitation regime. In this context, the conservation of every aquifer will acquire great importance. In particular, the mountain fractured aquifer could play an important role in water supply both for local population, which can exploit directly the resource, and for plain inhabitants. Mountain aquifer represent the main source of water for deep aquifers on the plains. Up to the present, the study of this type of aquifer have been considered through multiple methodology without the protocol. The aim of this work consists in the definition of the common methodology of approach for the study of every types of mountain aquifer. In this, the importance of the multidisciplinary approach is in evidence, but is very important the optimization of the research energies. For the calibration of the methodology, three mountain areas are chosen: Vigolana Massif, Saint Marcel valley and Livigno area.

## Study areas

The Vigolana Massif is characterized by high fractured rocks and karst conduit into carbonate rocks (limestone and dolomite). The difficulties for the study of this area are: the high vegetation cover, the impervious slopes, and the complex reconstruction of the conceptual model for the wide presence of the karst conduit in the massif.

The Saint Marcel area is constituted exclusively by crystalline rocks with sulfur mineralizations. The difficulty for the study of this area is principally the lack of outcrops.

The Livigno area and, in particular, the 'Gessi zone' are typical areas of high mountain. These are characterized by the presence both crystalline rocks and carbonate rocks.

There are also the presence of the extended rock glacier.

The difficulties in the data detection are also caused by the snow cover (till 4 meters) in the winter, by the presence of active rock glaciers and by the inaccessibility of a few zones. Another trouble is the too low temperature for the monitoring instrumentation: this causes the high costs for the monitoring and gets hard the quantification of the water resources.

## Results

*Vigolana Massif*

The calculation of the hydrologic balance highlights an excess of precipitation (8.18E+07 $m^3$/anno): this indicates that in the delimited basin come more water respect the water that go of the basin from the considered spring. For the peculiarity of the Vigolana massif, this has been considered, at spring tunnel scale, as a double permeability medium, where there are two portion of the mass with different permeability that feeds the spring conduit: the fracture of the rock mass and the rock matrix. The estimation of the exchange of water between the portion analyzed and the conduit gives indication about the possible exploitation of this water resource, preserving a minimum level. This exchange is 1.03E-05 m/s for each meter of variation of hydraulic head and for the unitary area: this flow will be through the conduit when $H_m > H_c$ and in the other way when $H_m < H_c$, where $H_m$ is the hydraulic head of the rock mass and $H_c$ is the hydraulic head of the conduit. In the first case occurs dry period instead of in the second one occurs rainy period.

*Saint Marcel area*

The Saint Marcel area has been studied considering the rock mass only as a fractured media and using natural tracers (sulfur mineralization).

The geo-structural analysis in the saturated portion of aquifer shows that the preferential flux directions have a trend towards the springs located in the bottom of the valley, along the slope. The mine drainage water goes along the same trend, making these spring vulnerable. In the saturated zone the hydraulic conductivity values are high along the dip direction opposite to the slope and to the hydraulic gradient, causing a decrease of spring flow in relation with rainy precipitation in the recharge area.

The chemical data reveal the presence of three group of water:
(a) $SO_4^{2-}$–$Ca^{2+}$-$Mg^{2+}$ rich water (mine drainage);
(b) $HCO_3^-$–$SO_4^{2-}$–$Ca^{2+}$ rich water;
(c) $HCO_3^-$–$Ca^{2+}$ rich water (fresh water).

In particular, the second group (b) of water results from the different percentage mixing between the first and the third waters: this mixing occurs near the Eva Verda spring and causes a sudden change of the physic-chemical characteristics of water and the consequently saturation of some element that precipitate as woodwardite. The low percentage of mine pollutants in the water of group (b) demonstrates that there is a high dilution with the fresh water: this indicates that the water of group (b) can be exploited for drinking.

*Livigno area*

In the Livigno area, in particular in the 'Gessi zone', the water circulation is principally into rock fractures. In this case the porosity of the rock matrix has not considered.

The high geological assortment and the difficulties for the direct analysis have not permitted the exactly estimation of the different type of the matrix volume.

The alternation of carbonate and sulfate rocks, which are subject to double porosity, gives the utilization of double porosity models unsuitable.

The 'Fontana dei Gessi' spring results a good water supply in the summer periods (35 L/s of flow) and a minimum annual flow (1.76E+05 $m^3$/anno) is guaranteed by the glacial flow.

## Discussion and Conclusion

For all mountain areas analyzed, the integration of more study and data analysis methodology has been important. To make a more orderly and methodical approach in the areas, the study took place in several phases:

1. an initial phase is characterized by the systematic collection of all existing data as possible on target area (geology, rainfall, temperature), the geological and geo-structural survey; this phase leads to a preliminary reconstruction of the geological map and the reference conceptual model;
2. the second step regards, where possible and necessary, the study through the geophysical survey to make more thorough and accurate the conceptual model, and the monitoring of water chemistry and flow of the springs;
3. finally, the phase of data analysis and integration for the quantification of phenomena:
   - for the carbonate and karst mountain aquifers, is performed considering the medium as dual permeability one;
   - for mountain aquifers in crystalline rocks, is performed considering the medium as a means of fractured pure. Often, the chemistry analysis of water of and the water-rock interactions through classical geochemistry methods has a high importance;
   - for all kinds of mountain aquifers the type of analysis depend on the precision with which you will be able to reconstruct the conceptual model in depth. In the case where knowledge of the subsoil is not complete, the analysis and quantification is executable considering the fractured medium as pure. In this case is essential to use the geochemistry.

The definition of a methodology, or rather a pattern to follow, depending on which type of mountain aquifer is focus of study, making it easier to approach more focused and less expensive.

The importance of knowing this type of aquifer is derived not only because they are sources of recharge for the most exploited aquifers of the plains, but also because they play a role in land management and civil engineering: changes in water pressure directly related to possible landslides in turn related to engineering infrastructure, construction of aqueducts, excavation of tunnels, often in mountainous areas are essential for a faster and less twisty roads.

The study more focused and more aware of these aquifers also allows the calibration and validation of analytical models for a specific type of aquifer, in particular, is very contemporary the approach about the double-porosity and dual permeability for the study of tunnels in karst aquifers.