25th ICC/ Pre-Conference Tutorial

3D DIGITIZATION IN CARTOGRAPHIC HERITAGE

Scanning historical globes and deformed maps

Paris, 2 July 2011

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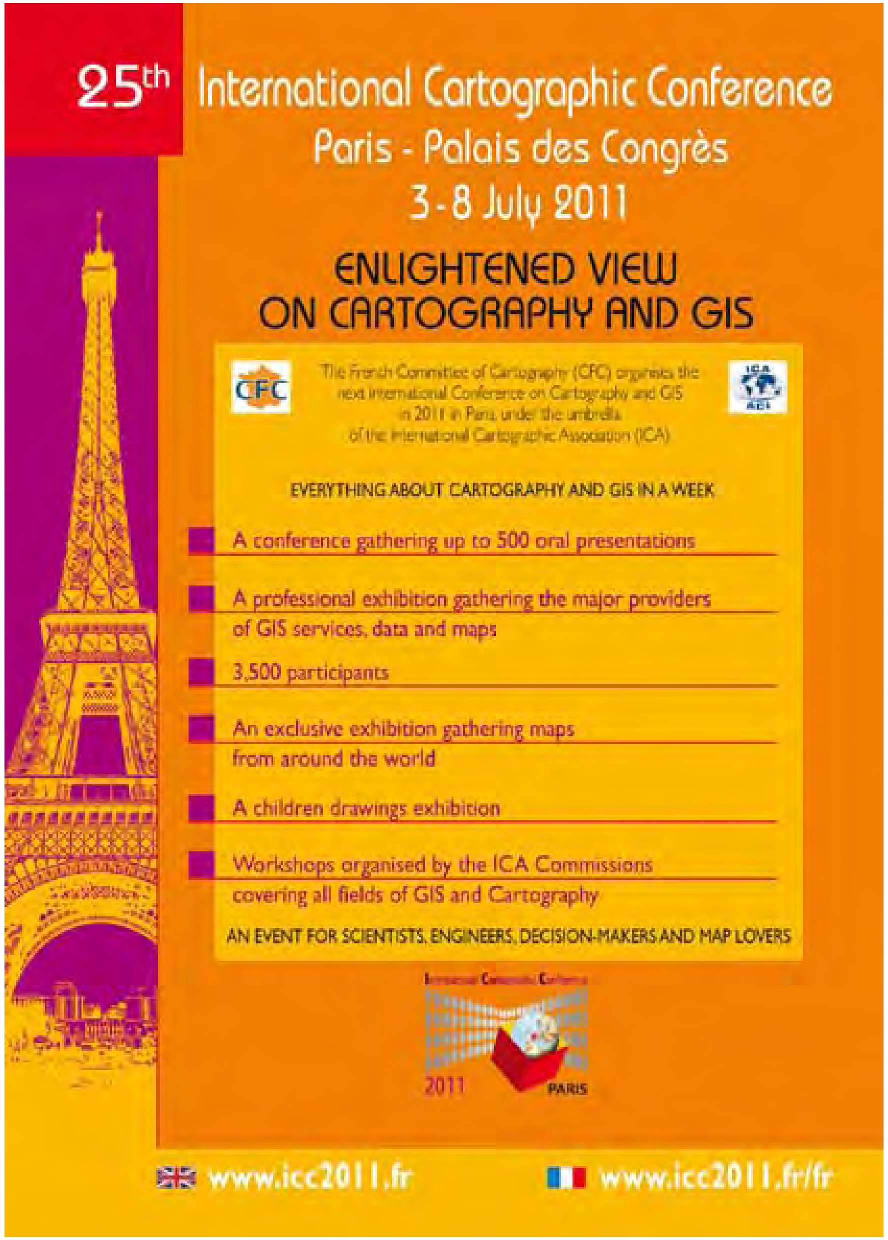
25th International Cartographic Conference
Paris - Palais des Congrès
3-8 July 2011
ENLIGHTENED VIEW
ON CARTOGRAPHY AND GIS
CFC
The French Committee of Cartography (CFC) organises the next International Conference on Cartography and GIS in 2011 in Paris under the umbrella of the International Cartographic Association (ICA)
ICA ACI
EVERYTHING ABOUT CARTOGRAPHY AND GIS IN A WEEK
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A professional exhibition gathering the major providers of GIS services, data and maps
3,500 participants
An exclusive exhibition gathering maps from around the world
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Workshops organised by the ICA Commissions covering all fields of GIS and Cartography
AN EVENT FOR SCIENTISTS, ENGINEERS, DECISION-MAKERS AND MAP LOVERS
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Digital Technologies in Cartographic Heritage
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Cartographic heritage is a component of the overall world's cultural heritage. It concerns specifically all the valuables which are or may be inherited from historic cartography and maps. It concerns also all the cartography heirs who are the receivers of the benefits offered by cartography, maps and mapmaking of the past. Cartographic heritage issues are thus addressed not only to experts but also to society and to the general public.
The digital approaches to cartographic heritage is a meeting area of modern cartography digital mainstream and of history of cartography, maps and mapmaking.
Coming event:
3D DIGITIZATION IN CARTOGRAPHIC HERITAGE
Scanning Globes and Deformed Maps
Tutorial, Paris 2 July 2011, BnF
More >>

PROGRAMME

09:30
Introduction

10:00-13:00 **HISTORICAL GLOBES**
-3d scanning of historic globes;
-Analysis of 3d globe digitization;
-Digital representation and visualization (virtual and cartographic projection);
-Practical demonstration (scanning, processing and mapping).

13:00-14:00
Lunch

14:00-17:00 **DEFORMED MAPS**
-3D photogrammetric acquisition;
-3d scanning digitization;
-Processing and analysis of 3d photogrammetric model and comparison of photogrammetric and laserscanning model;
-Digital representation
-Practical demonstration

17:00
Closing

The Tutorial is based on in-situ implementation of 3D digitization with the use of 3D data capturing instrumentation (3D scanner, 3D photo-cameras).

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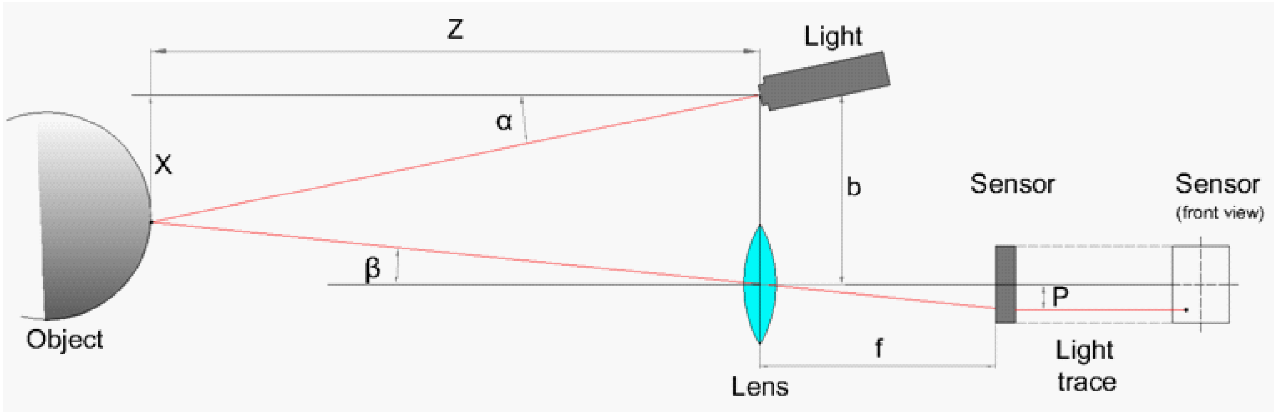
Paolo Vernier is a PhD holder and researcher at the IUAV Photogrammetry Lab.

HISTORICAL GLOBES

Studying the globes, the significance of the disciplines that study the shape and representation of the Earth becomes apparent from the methodical point of view as well as for the application of new digital technologies.
Indeed it will become clear that, as a consequence of the necessary approximation and scale differences, the representation and study systems recall those used for the Earth. Some aspects and problems typical of Geodesy will also be highlighted, such as those related to coordinate systems and reference surfaces, even if applied to cartographic globes. Furthermore, the globes represent the exemplification of the problem known since ancient times of unrolling a double curvature surface on a plan. Other than studying their shape, it will also be important to recognize their cartographic content.
We intend to improve the knowledge of their cartographic value under the double aspect of the material support and the depicted (or applied) cartography. As for geometry, we intend to verify if the wooden support was built according to an ideal spherical shape or if some adjustments were planned to resemble the actual shape, even if it is clearly impossible to consider them as physical models of the geoid. The central focus becomes therefore the transition from the sphere as an art object to the globe, intended as cartography to all intents and purposes. All these analyses allow defining a virtual sphere made of two different aspects: the geometry of the wooden support and the cartography extracted directly from the globe.
The tutorial has been grouped in different steps:
-3d scanning of historic globes;
-Analysis of 3d globe digitization;
-Digital representation and visualization (virtual and cartographic projection);

3D SCANNING OF HISTORIC GLOBES: THE SHAPE

The first part of the work consists in the survey of the sphere, typically a wooden structure covered with fabric, stucco and other materials, representing the physical support for the cartographic surface. The knowledge of the three-dimensional shape is undoubtedly research topic of high interest and, consequently, it is studied in different fields, from



Scheme of a 3d scanner based on the triangulation principle industry (in which reverse engineering emerges) to cultural heritage. First of all, the knowledge of the shape is necessary to understand if there was a project held under the generic term of sphere. In fact, it will be interesting to understand if the globe has a precisely round shape or not, and possibly to study, by representing deformations, the differences from the ideal shape, trying to attribute it to the project or to the effects of usage and time.

The problems about surveying the shape of a wooden sphere require an accurate selection of the measuring method, in order to address the problems due to the working environment and the object under study itself. The selection of the survey method should also consider the expected result itself, from a qualitative and quantitative point of view. The point cloud, which seems to be the survey goal, can be obtained in different ways and have different characteristics. It is important to establish the number of points (in terms of accuracy on the object), but most of all the precision in terms of XYZ coordinates of each point, in order to obtain an accurate estimate of the final sphere.

Different methods and instruments can be used for these analyses and each one of them allows to achieve different results. From our tests the most suitable instruments are the ***scanner 3d*** (or range camera) ***based on the triangulation principle.***

Generally, these instruments consist in a known light source and a sensor, closely linked together. The light source, of different kinds depending on the instrument used, emits a laser stripe recorded by a sensor, for example a digital camera. With this method source center, projection center on the sensor and laser dot projected on the object form a triangle, with some known elements (distance between light source, sensor and the angle of the laser emitter) and others that can be calculated (position of the reflected point).

Triangulation acquisition systems have basically two advantages. In these active measurements systems the instrument acquires the studied surface automatically, provided that there is enough light, thus reducing acquisition time and the operating procedures required. The other advantage is the measurement quality. The resolution (i.e. the point density on the surface) and precision level are strictly related to the instrument used; we can easily reach resolutions of 1/10 mm and the instrumental uncertainty down to 25ηm. These values directly affect the resulting model and therefore the description of the three-dimensional shape recorded. Moreover range cameras do not require the application of positioning targets on the surveyed object, nor the materialization of a reference system and allow the simultaneous acquisition of geometric and radiometric information.

In the case of the cartographic globe we used the Vivid 910 laser scanner, by Minolta. The choice was made by experimental tests, which showed a better operating mode compared to other instruments.

Characteristics:
calibrated optics: Long f=25 mm
Medium f=14 mm
Wide f= 8 mm
acquisition distance: 50 to 250 cm
acquisition area: 9.3 x 6.9 x 2.6 cm
to 149.5 x 112.1 x 175.0 cm
positioning targets: not required
accuracy: ± 0.05 mm
acquisition time: 2.5 sec
RGB value acquisition: yes

The globe was acquired using a Medium,lens at a distance of ca. 70 cm from the globe's surface. Even though it would have been possible to increase this distance to obtain a larger acquisition area, we chose a 70 cm operating distance to guarantee the object resolution required to read the semantic content of the cartography.

In the step of data processing by observing the triangulated mesh of a single cloud, we will notice that the surface is not smooth, but has features, i.e. discontinuities caused by various factors. In particular, scanners detected some discontinuities in overlapping areas of two gores, and there is actually a variation compared to the general curvature.

However, all scans highlight other discontinuities that are not actually visible on the object.

After accurate observation, it appears clear that these discontinuities correspond to cartographic zones where the transition from bright to dark elements is abrupt. In this example, it results clear that the coast line is a three-dimensional element, because of the transition from bright land to dark water. In the middle of the ocean, we can also notice islands in relief and, in the figure, the corrugation effect is clearly due to the presence of bright writings on a dark background. This finding allows on one hand an approximate reading of the cartographic surface starting from the scan, even before we start using the textures acquired.

However, discontinuities, both physical and real, are significant, because they characterize univocally part of the globe, i.e. the scanned spherical cap, that would otherwise have been difficult to record.

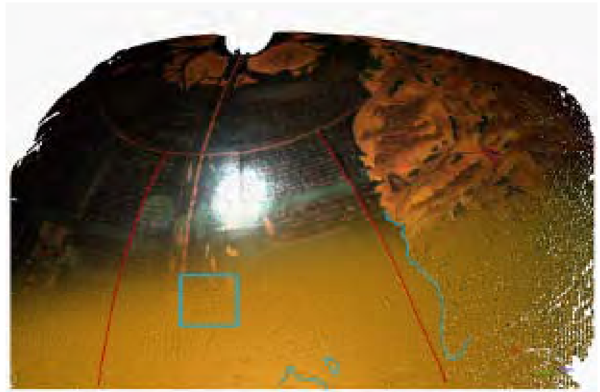
After this observation, globe data processing keeps on with the known pipeline which schedules the registration of all range maps in a single reference system. Between different strategies of registration, for globes we used the cloud on cloud registration method by the ICP (Iterative Closest Point) algorithm. This approach have been preferred thanks to the presence of discontinuities on the acquired surface and the RGB value of the range map.

At the end of data processing the final result is a 3d model of the globe with high accuracy. From the model we can extract horizontal and vertical profiles to verify the dimensions of the wooden sphere.

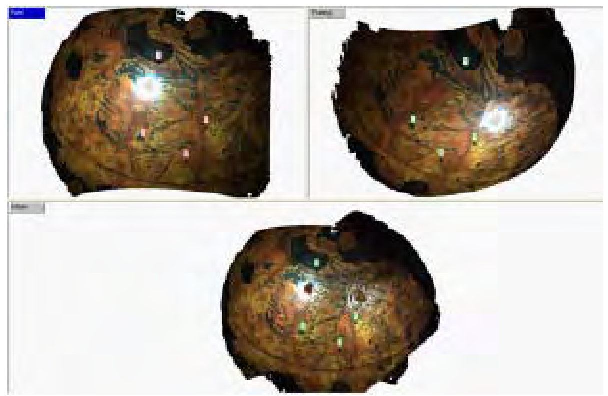
Analysis of 3D globe digitization

However, the most interesting aspect is the possibility of studying the shape of the globe and its possible deformations. This analysis can be conducted starting from the deformations of the model generated by the laser scanner compared to the best interpolating sphere. The first step consists in determining the best fitting sphere, achievable with reverse engineering software as Rapidform, Geomagic and ad hoc software realized by us.

Moreover, by writing this and the following software, we obtained an application specific to cartographic globes, capable of highlighting significant aspects of the sphere under study



Detail of a single point cloud with RGB value



Point clouds registration in a single Reference System by ICP algorithm

such as center, radius, curvature, deformations, residuals, etc. The software calculates the least squares solution to obtain an estimate of the best interpolating sphere.
Now we can determine the globe's deformation compared to the ideal sphere, according to the classical cartographic problem of representing the equipotential surface of a geoid compared to the reference surface of the ellipsoid. In this case, the reference surface is further simplified and corresponds to the interpolating sphere previously calculated.

Specifically, in the software "Points", written for this application, deformation is expressed by means of an m x n matrix, with m = longitude e n = latitude, where the value in each single cell derives from the difference between the ray of the interpolating sphere and the ray calculated for that point. To obtain the matrix we choose, in order to simplify calculations, to perform a translation so that the sphere's center has coordinates (0,0,0). Subsequently, each point of the model has been transformed from Cartesian to spherical coordinates using the formulas.

$\lambda = \mathrm{arctg}\,(y/x)$

$\phi = \mathrm{arctg}\,(z/\sqrt{x^2+y^2})$

$R=\sqrt{x^2+y^2+z^2}$

Then we generate the matrix with values λ and ϕ as row and column indexes, while we enter in the cell the difference between the radius Rxyz (distance between the centre of the best fit sphere and the point P of coordinates x,y,z) and Rsph radius of the best fit sphere.
The matrix is finally interpolated in Surfer with Kriging's algorithm and then represented according to an equirectangular projection. Therefore, we obtain false color representations, or contour line representations, that we can superimpose on the globe's cartography to distinguish which parts of the cartography show the biggest deformation, due to the modifications in the wooden support.
The representation of the deformation obtained with this method provides information about the position of the main deformations regarding both the module (difference between the calculated radius and R0) and the direction of the deformation, outwards or toward the center of the sphere itself. However, the three-dimensional visualization of this effect is limited by the unfolding on the plane of the calculated deformations.
To allow a better understanding of the deformations, we wrote another software application which generates a three-dimensional representation of the deformed sphere, following the example of the classical representations of the geoid.
In this case, the coordinates of each point of the surveyed surface represent the starting point. By applying the formulas previously seen, each point has been transformed into spherical coordinates λ and ϕ and the radius Rxyz where radius is the distance between the centre of the best fit sphere and the point P of coordinates x,y,z.

finale 3d model of the globe

Then we calculate the difference between Rxyz and the radius Rsph of the best fit sphere to found Δr : Rxyz - Rsph = Δr

Then the value Δr is amplified for a scale factor S, so: Δrnew= Δr x S

In the final model the radius is calculated: Rpotato= Rsph + Δrnew

so each point P is represented by λ ϕ Δrnew and the it is transformed in P xyz potato .

In this way, we obtain the equivalent of the classical cartographic representations, where the Z value is enhanced by a known factor. In cartography these are the so called two-and-a-half-dimensional representations, while the deformed model obtained is definitely three-dimensional. It can be viewed in the 3D space and we can use all spatial navigation operations typical of three-dimensional models.

Moreover it's possible to attribute a color to each point function of the real RGB value of the point (from the cartographic surface) or of the dimension of Δrnew.

There is also the possibility to obtain some slices to represent the punctual value of deformation. This operation cannot be done on the real sphere because deformations have a little value and it is not possible to apply the exaggeration only to the value of deformation. Instead it is possible to apply the scale factor to spherical coordinates because we can amplify only the radius value.

Digital representation and visualization the cartographic surface

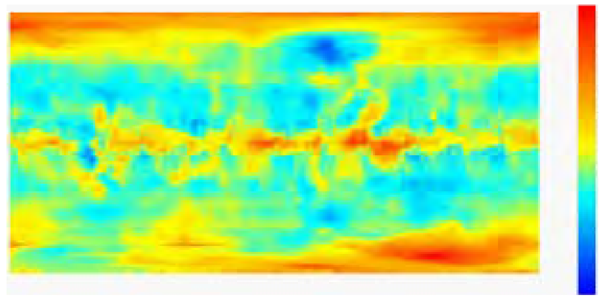
Once we determined the shape of the wooden sphere, the next step is the survey of the cartographic surface. Our goal is to obtain an exhaustive knowledge of the cartographic globe, by assigning a cartographic content to the wooden support. The first step of the procedure is photographic acquisition by calibrated high resolution digital camera.

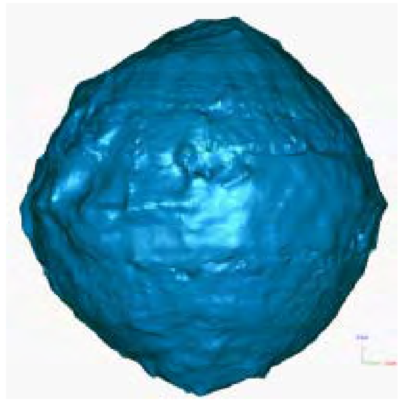
This operation, apparently free of issues, encountered many difficulties due to the spherical characteristics of the object.

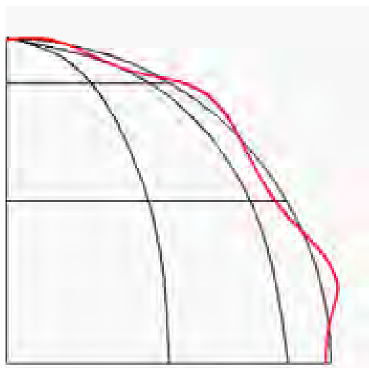
Proceeding with the proposed process, the next step is the orientation of film frames. The goal of this phase is to position film frames where they were when the picture was taken. We used the software NM3-digit based on D.L.T. (Direct Linear Transformation) realized by the Photogrammetry laboratory of CIRCE IUAV some years ago.

This method presents the great advantage of solving the internal and external orientation, as seen above, of images acquired with non-metric digital cameras. It is however necessary to follow some indications related to the number of control points acquired and to their placement. In fact, for the algorithm to generate an accurate convergence, it is necessary to acquire more three-dimensional points in order to estimate the parameters.

When applying the D.L.T. to the survey of the globes' surface, we want to identify the coordinates of the camera center, needed in the following phases of the analysis. To orient the film frames, the control







a) 2d map of deformation
b) 3d globe with exaggeration of deformation
c) exaggerated deformed section (red)

points have been acquired directly from the range map sets oriented in a single reference system, by recognizing the point on the image through the RGB color values of each single point. It is important to choose those points which allow to have a strongly 3d distribution.
In the last phase of this process, we move from the spherical surface to a known projection, considering the well known cartographic problem of the projection of a double curve surface.
Like for the Earth's surface, the link between a point on the surface and one on the map is not immediate, but it is solved by means of a reference surface of known and simplified geometry. When we consider the Earth, the surface used is the rotational ellipsoid, while when we consider cartographic globes the geometrical shape used is the sphere. This approximation is introduced to bypass the deformation of the wooden sphere during the reprojection of the cartographic sphere.The suggested method aims to obtain a digital picture positioned in a given cartographic projection. By writing the software, we obtained a custom product that can be used on the cartographic globes. At the same time, we implemented and tested an algorithm specific for the sphere. Combined with the application described above, we created a software package useful to the examination of the globes under study.
For this application we wrote a custom software to associate the spherical coordinates, describing the sphere's points, to the pixels of the oriented digital image. The algorithm creates an empty image (matrix), where its coordinates ϕ, λ are the spherical coordinates of the model.
As shown in the scheme, for a better understanding the software can be subdivided in smaller modules.
In the first module, we create the reference surface. By using the classic sphere formula and determining the angular step in latitude and longitude, it is possible to reconstruct a sphere of known center and radius, according to the formulas that allow to transform spherical coordinates into Cartesian coordinates:

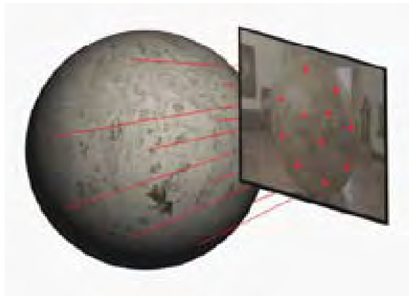
$x = R \cos\phi \, \cos\lambda$

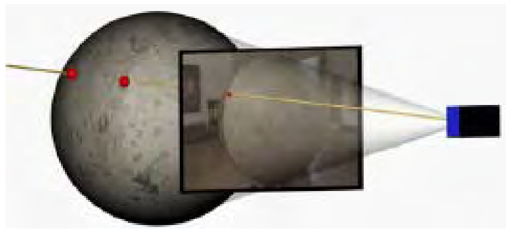
$y = R \cos\phi \, \sin\lambda$

$z = R \sin\phi$

with ϕ = vertical angle (Latitude) e λ= horizontal angle (Longitude).

In the second module, we calculate the correspondence between each point of the reference system and the pixels of the oriented image. The equations are those used by the D.L.T. algorithm, which, once given the parameters calculated in the previous phase and object coordinates of the point, allow the identification of the corresponding pixel.
Once we identified the pixel, it is possible to extract its RGB value. However, as shown in the diagram, each pixel of the image can correspond to two distinct spatial points, because the sphere is a round shaped object. To avoid this effect, we searched for an empirical method to place the



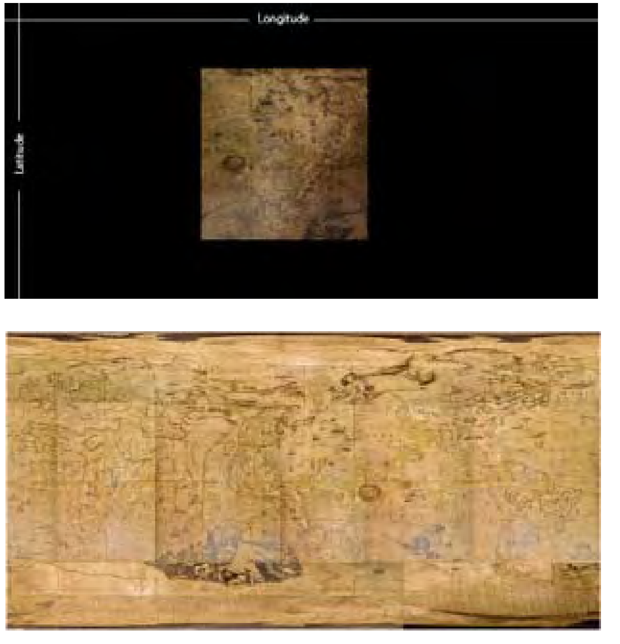


a) scheme of DLT orientation
b) scheme of the correspondence globe-image-camera

color extracted from the pixel onto the precise corresponding point.
Finally, in the third module, we build the final matrix. On a grid characterized by the angular step set in the first part of the procedure, we insert the RGB color values extracted from the pixels corresponding to the surface points. If during the computation there is no correspondence between an image point and a globe point, the corresponding cell in the matrix is filled with a constant value (black). This situation happens regularly in the areas of the image where we do not see the globe, but the surrounding environment.
The resulting matrix can be imported in Matlab and therefore reprojected, choosing each time the cartographic projection most suitable for our representation requirements.
At the same time, the software creates an image in a known projection, the equirectangular one, where the longitudinal degree is equal to the latitudinal degree for each point.
Of course, the rows and columns size of the matrix corresponds to the dimensions of the digital image and is determined by the angular step chosen. For example, if we choose a angular step equal to 0. 1°, the matrix and the finale image will have the following sizes: 3600 pixel (360°/0.1°) in width-longitude and 1800 (180°/0.1°) in height-latitude.
To obtain the final cartography, the last phase is image composition. If the images are realized with the same angular step, there is no necessity of mosaicking because they have the same dimension, and so the same reference system. Simply it's necessary cut images and realize a radiometric correction.
Even if we choose to compute a little part of the initial image, the dimensions of the final one don't change because they are set by the angular step. In this way the pixel is always referenced in the same reference system of the image which corresponds to the geographical one.
The final map shows only some problems in the polar area where meridians are not exactly parallel, but convergent. We have also to notice that the equirectangular projection is not suitable to represent the polar area.
The final map obtained from the globe represents a very interest document because it contains all cartographic contents – semantic, projective, metric- , but there are also many information connected with the story of the globe as a material object.
This document becomes really important when we don't have any other source for the study of globes . The high resolution we can reach in the reprojection step allows us to analize not only the main feature, but also the details, writings and other themes. Moreover the availability of a flat map of the spherical surface allows many other studies and comparison with different maps.

Virtual Globe

New technological digital devices allowed , both to visualize the 3d virtual globe and to conduct tests on it. The available literature includes examples of digital representations of historical globes,



a) reprojection of a single image
b) mosaic of reprojected images

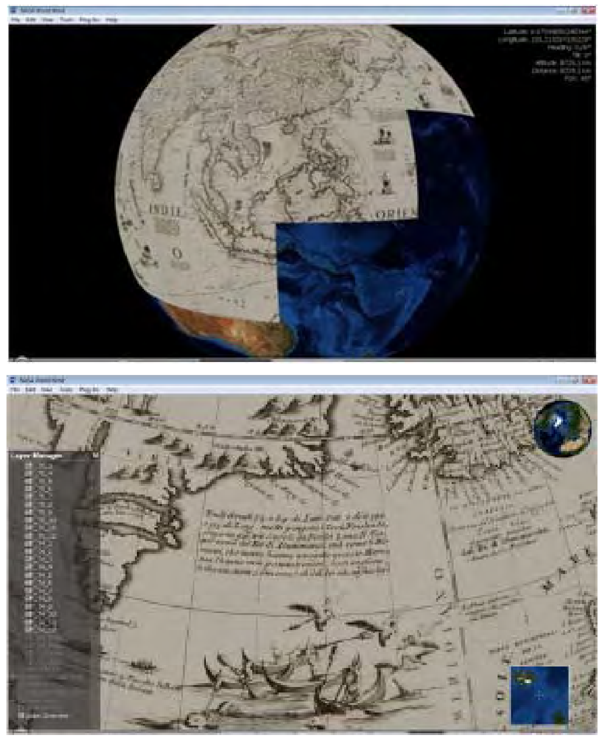
from Mercator’s globe to the research project on Behaim’s globe. The goal of these digital models is primarily to explore the possibility of navigating the globe using monitors or hyperglobes, as they relate to the fruition of the cartographic globes.

Nasa World Wind

The first virtual globe application was designed using NASA’s World Wind software, the code of which has been made available for use and modification under an open source license.
The software was meant to manage satellite imagery, uploaded in real time on a virtual sphere. The software displays the geographic grid and also other geographic elements such as political borders and toponymy.
The surface of the sphere was created using different files, each corresponding to one gore. This method improved the management of system memory, as opposed to using a single file including Coronelli’s entire globe cartography. We used all 48 gores, while the polar ice caps were also divided in 12 gores each. Images were uploaded into the software using png format, to guarantee images of high quality and limit the file size at the same time. The image set used has the highest resolution (pixel size 0.1 mm), but we prepared other image sets at lower resolutions, to use in case the computer memory was not sufficient to handle the highest resolution.
Georeferencing was added by entering the geographic coordinates of the 4 vertices for each image. For each image it is also possible to specify the transparency level to allow the comparison with the satellite image underneath.
As we can see in the images below, the software guarantees an excellent visualization of the cartography, enabling not only navigation but also the reading of all the elements present on the surface.
To facilitate navigation we can use visual references on the right side of the screen, showing the current position against the actual satellite cartography. Finally, we can perform standard queries to know the coordinates of a point and the distance between two points on the spherical surface.

Coronelli’s Virtual globe

The choice of writing specific software for the Coronelli’s globe was due to the need for software that, in addition to virtual navigation, would allow the visualization of certain characteristics emerged during the analysis. This is an “open” software program where new features can be progressively implemented.
The software surveys the sphere by using the classic functions of rotating and zooming. However, compared to the previous application, it allows to view the map in different ways. Usually, we have the classic view of the digital globe, where the map image is mapped on the sphere. However, there is the possibility to change view and select a plane representation among those codified in cartography. Currently, the plane view corresponds to the equirectangular projection, but



Screenshots of Nasa World Wind

other projections can be implemented, depending on the focal area.

The software, written in Delphi language, also allows the overlapping of several images, both raster and vectorial. On the sphere we can overlap: the original cartography, taken from the globe; a current satellite image; and Coronelli's cartography, modified with respect to the Greenwich Meridian (this topic will be discussed in the following chapters).

As for vector elements, it is currently possible to upload the geographic grid with the same latitudinal and longitudinal graduation of the globe (parallels and meridians every 5°) and current geographic borders. Another interesting application to the study of the globe is, for example, uploading the course of explorations as shown on the map, to verify the course tracking and therefore verify if errors are due to imprecise sources or to inaccurate course tracking.

It Both with raster images and vectorial features, the overlapping is immediate if we have georeferencing files available. The images uploaded so far into the software are in equirectangular projection and are automatically mapped on the spherical surface, too. Vectorial files, instead, are made of shape files, and are therefore georeferenced.

It is finally possible to import new zone maps to overlap as well, including maps smaller than the globe. In this case, georeferencing is accomplished by shifting and rotating the new map, until the overlap is as accurate as possible.

REFERENCES

-Adami A., 2009 From real to virtual globe: new technologies for digital
cartographic representation, e-Perimetron, Vol. 4 No. 3, 144-160

-Adami A., Guerra F, 2008. Coronelli's Virtual Globe, e-Perimetron, Vol. 3, No. 4, 243-250.

-Boutoura C. 2006. Assigning map projections to portolan maps, e-Perimetron, Vol. 1, No. 1, 40-50.

-Boutoura C., Livieratos E., 2006. Some fundamentals for the study of the geometry of early maps by comparative
methods, e-Perimetron, Vol. 1, No. 1, 60-70.

-Hruby F., Riedl A., Tomberger H., 2008. Virtual representations of antique globes - new ways of touching the untouchable, International Journal of Digital Earth, Vol. 1, Issue 1.

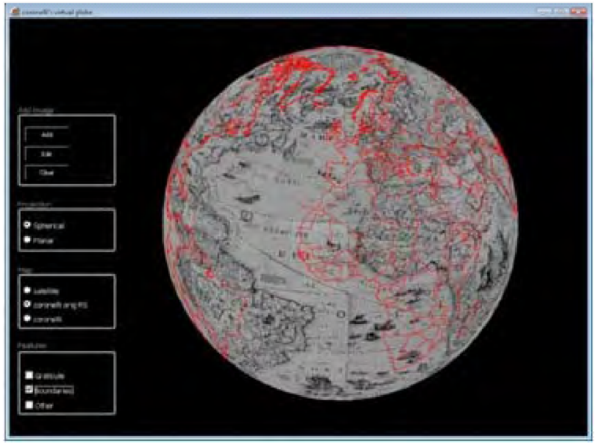
SOFTWARE:

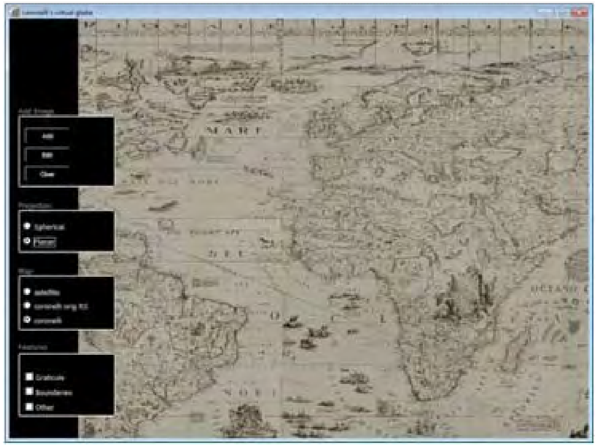
-Geomagic studio
www.geomagic.com

-Nasa World Wind
http://worldwind.arc.nasa.gov/java/

INSTRUMENTS

-Minolta Vivid 9i
http://www.konicaminolta.com/sensingusa/products/3D-Scanning





Screenshots of Coronelli Virtual Globe

Deformed Maps

The digitization of documents and graphs (maps, sketches, photographs, paintings, etc) has been spread widely during the last years. A good indication of the great extent of documents' digitization can be extracted by examining the number of funded Research Programmes and total amount of funds given by the national and international organizations such as the National Science Foundation of US and the Frame Programmes of EU. Specifically, in the European Union a large amount of money has been given to Universities, Research Institutes and Commercial Organizations through the Information and Communication Technologies (ICT) Work Programme to produce digital resources of important cultural items. For example, "DIGMAP-Discovering our Past World with Digitized Historical Maps" is the title of a recently funded project in EU and its main aim is to provide a solution for flexible services for registering, searching and browsing in collections of digitized historical maps (DIGIMAP, 2008).

The digitization of historical maps is a very hard task and although it seems a trivial job certain limitations and conditions might lead to either the incomplete or incorrect production of their digital replicas.

The standard geometric resolution of the produced digital copies of analogue documents, able to provide an exact replica of the original, has been set to 300 pixels per inch (ppi). In such a resolution the pixel size is about 80µm and possible erroneous artifacts created by the digitization process can not be perceived by the common human vision when a printing reproduction of the digital copy is produced. The 20-20 vision of humans has a resolution of 0,2-0,3 mm in the reading distance of 20-25cm and the possible misalignment of 80µm can not be recognized on the printed graphs (maps, sketches, photographs etc).

Both the geometric and radiometric accuracy of the digitized copy are very important. However, in this paper only the geometric content of digitized maps is examined. The digitization can be performed through several possible ways. It is depending on the purpose of the digitization and the nature and sensitivity of the original which method to use in order to provide the most accurate and best possible results.

Generally, historical maps lie on paper subject and a conventional 2D processing, recording and visualization might be the best practice.

The 2D photogrammetric approach in the digitization of a historic map has given good results in the past (Tsioukas, et. al., 2003). Instead of using a contact scanning device, a remote capture of the map's image can lead, after a digital rectification process, to a digital ortho projection of the original. In case the camera sensor's resolution is not adequate to capture in a single shot the whole historical map, several orthorectified images can be merged together to provide in a single mosaic a digital copy of the minimum 300ppi resolution.

However, in some cases 3D digitization might be the one and only procedure to use. The reason to

Fabric map of France (early 20th century) use 3D recording of the map might be one or more of the following:

- bad condition of the original that prevent its enforcement during conventional scanning
- the map lies on 3D subject (map on wood, fabric and on other non-flat materials)
- the map is part of a valuable old document book (atlas)
- the current map's form has been changed to 3D since its original 2D production

3D Photogrammetric Recording of objects has contributed the most in Cartography, Surveying and other scientific disciplines such as Architecture and Archaeology. It has been invented and evolved in parallel with photography and has been used to restitute objects that extent in 3D since the 19th century. Its use is suggested especially for the recording of objects that are either fragile or placed far away from the recorder. Therefore, its use has been naturally extended for the recording of artifacts and generally objects that have great cultural values especially findings from archaeological excavations but also for paper documents such as historical maps.

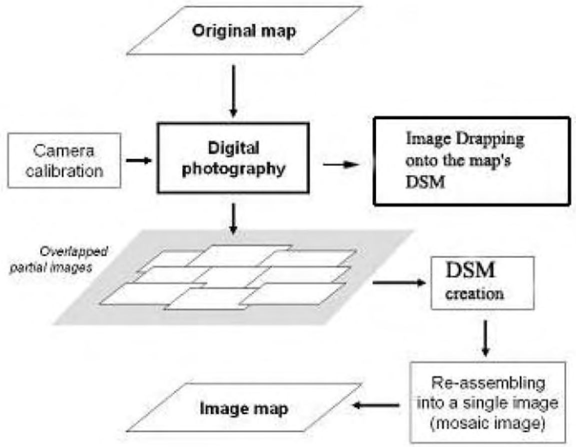
However, the use of a digital camera to record a historical map does not guarantee its precise documentation since a detailed calibration process and control field measurements have to be realized prior to the photogrammetric processing. Gross errors of camera lenses (radial distortion) will affect badly and provide erroneous digital products. In the case, where the historical map is not planar and there exist even a small anaglyph, the rectification procedure and the radial distortion error imposed by the lens, affect the correctness of the final product especially when this is provided through a mosaic of several rectified images.

The simple 2D recording (and possible mosaicing) of rectified images coming from digital photographs of the historical map may lead to a correct final product only when:

- the map is flat or can be flattened by applying special mechanical enforcement
- proper calibration and radial distortion removal has been performed
- blending is applied to merge several rectified partial images of the historical map

When the map cannot be flattened or is by nature anaglyph, 3D recording has to be applied. Generally, all objects are 3D and some of them may be characterized as 4D especially those that are flexible and may be changed in shape and size through time (fig 1). Such objects can also be the historical maps. Due to their deformation through the ages which can be both permanent and irreversible a full 3D stereoscoping process has to be applied to record the Digital Surface of the map's subject and its pictorial representation that can be an ortho image.

Additionally, the 3D historical maps and paper maps stored in books (atlases) need 3D recording which can be provided through the above mentioned methods (Adami, et. al. 2007, J. Niederoest, 2003). Several devices and systems have been proposed by commercial companies (Arius 3D, XYZRGB) that



The flowchart of the transformation of the original map to its digital form and the necessary elaborations are using typical photogrammetric procedures and stereoscopic configuration or special structure light or laser light algorithms to provide in full 3D the model of valuable small objects.

3D Photogrammetric Acquisition

Our proposal is based in the stereoscopic image capturing and automatic generation of Digital Surface Models (DSMs) of the maps' surface. Classical photogrammetric approach of close range applications has been adopted with a slight exception. Instead of using a single lens camera we applied stereophotography using the FujiFilm real 3D W1 stereoscopic digital camera (fig. 3), to achieve:

- better connection between the frames
- the ability to determine in a single shot project the ground truth 3D model of the objects with no use of GCPs

The process we follow in the tutorial is illustrated in the flowchart. The historical map is transformed into its digital form by the method of the digital photography and the modern photogram-metric software providing point clouds using heuristic algorithms for image matching. The process is non contact and harmless for the maps. Our main target and concern is to create a 1:1 digital facsimile copy of the analogue map. When this requirement is not fulfilled due to the dimensions of the map, a greater number of stereoscopic images are captured.

At this stage of the work, a number of parameters that is of crucial importance is taken into consideration. First of all, the shooting distance should be sufficient for a 1:1 final copy and this means that the images must be taken in larger scale than the actual map's scale. We are not obliged to capture vertical shots however verticality might help to achieve a better and more robust photogrammetric solution. Our concept is to calculate and produce the Digital Surface Model (DSM) of every part of the map. The models are automatically merged and registered using the built in software capabilities (Photomodeler Scanner or Agisoft PhotoScan Professional) to avoid manual collection of common points and

Stereoscopic camera manufactured by FujiFilm mergers. The captured scenes provide also the texture information and an overall 3D model in various formats might be exported and used in other applications. The 3D model of the map might be created with no use of additional measurements providing a good relative model. Proper calibration method must proceed to determine the base distance between the two lenses of the stereoscopic sensor and it can be imported as an additional information to create a true 3D model of the historical map. Additionally, the user can perform simple measurements to provide the correct scale information of the model.

3D scanner acquisition

Another possibily in 3d map digitization , as we explained before, is the use of a range camera based on a triangulation syste. The availability of a range camera will allow the comparison between the two different approaches: the photogrammetric one and the laserscanner.

The comparison concerns surely the results, in term of geometric accuracy and color reliability but also other aspects such as the acquisition process, the necessity of specialists, the complexity and availability of instruments and softwares.

Bibliography

-Adami A., Fregonese L., Guerra F., Livieratos L., Tsioukas V., (2007) Digital Representations And Analysis Of Deformations Induced In Map Supporting Materials, Proc. of CIPA-2007 International Symposium, Athens, Greece, Oct. 1-6. 2007

-Arius 3D-Imaging the real world, *http://www.arius3d.com/* (Assessed 28 Jun. 2011)

-Creaform-Handyscan 3D, *http://www.creaform3d.com/en/default.aspx* (Assessed 28 Jun. 2011)

-DIGMAP-Discovering our Past World with Digitized Historical Maps *http://ec.europa.eu/information_society/activities/econtentplus/projects/cult/digmap/index_en.htm* (Assessed 28 Jun. 2011)

-Daniil, M., (2007), Digitization Technologies of especial Historical, Artistic and Scientific Graphs, Ph.D. Dissertation (in Greek), Dept. of Architecture, DUTH, Xanthi, Greece, 2007.

-Makarona C., Koutsoudis A., Arnaoutoglou F., Tsirliganis N., Stratis J. A., Chamzas C., Towards a Complete Digitisation of Post Byzantine Icons, 3d Colour Laser Scanning Conference, 27-28 March 2008, London

-Niederoest, J., 2003: A birds' eye view on Switzerland in the 18th century: 3D reconstruction and analysis of a historical relief model. Maps, Proc. of CIPA-2003 International Symposium, Antalya, Turkey, Sept. 29-Oct. 4, 2003

-Tsioukas V., Daniil M., Livieratos E.,Possibilities and Problems in Close Range Non-Contact 1:1

Digitalization of Antique Map, e-Perimetron, Vol.1, No. 3, Summer 2006 [230-238]
-Tsioukas V., Daniil M., 3D digitization of historical maps, e-Perimetron, Vol.4, No. 1, Winter 2011 [45-52]
-XYXRGB-Image is everything, *http://www.xyzrgb.com/industrial_scanning.html* (Assessed 28 Jun. 2011)

Software

-PhotoModeler scanner 2011
www.photomodeler.com
-Agisoft Stereoscan
www.agisoft.ru/products/stereoscan/

Instruments

-FujiFilm Real 3D W1
www.fujifilm.com/products/3d/camera/finepix_real3dw1/