DIGITAL REPRESENTATIONS AND ANALYSIS OF DEFORMATIONS INDUCED IN MAP SUPPORTING MATERIALS

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ABSTRACT:

Historical maps often suffer significant deformations of their supporting material of any type. These deformations make it difficult to make an accurate reading of maps in its geometric and semantic context. As invaluable materials of cultural heritage, historical maps, in very many cases (rolled parchments, maps in old books and atlases etc.) cannot be put through a scanning process requiring a plane positioning of the map supporting surface, which is usually undulated. Digital photography is then an alternative if certain technical details are fulfilled.
In order to capture the undulated map surfaces due to the curvilinear deformation of their supporting material, the research group proposed use of three dimensional (3D) laser scanning. With this new digital technology, capturing such map surfaces gives a cloud of points with an uncertainty of about 0.1 mm, which forms the initial 3D model of the surface. From the point cloud we can pass to deformation analyses using processing based on proper types of finite element models. In some simpler cases it is enough to define a parametric interpolated surface which is easier to manipulate as far as the memorization and the transmission is concerned.
One problem in this approach is setting up an external reference system for the 3D scanning and the associated photogrammetric survey of the map surface, giving the necessary imagery to the point cloud. Since it is not possible to attach control points on the map surface, the referencing is assured by non contact control mechanisms.
The next step is the digital photogrammetric survey using high-resolution calibrated cameras.
The external control is common with the reference system of the laser scanning in a way to preserve the uniformity of both the geometric and the radiometric data. For the latter, special samples of colour standards are taken during the capturing session.
The procedure described here gives a metrically accurate model of high precision with the same time high image fidelity. All types of deformation analyses are then possible, applying the strain tensor approach in order to depict, via invariants, the deviations of the map supporting material from well fitted regular surfaces. Given that the map supporting material has physical properties, a stress-strain analysis is then suitable.

1. INTRODUCTION

Historical cartography is a very important sector of artistic and cultural heritage and as such, it is the subject of extensive and specialized analysis. There are many scientific fields which involve historical cartography, such as the analysis of semantic, symbolic and geometrical content of maps, the study of the projective nature of charts, the comparison between different maps and many others. The further element which arouses much interest is the recording of historical maps, either for the realization of historical archives or for a wider diffusion and sharing.
Whether the main interest is the analytical study, or the archiving of historical maps, the most suitable instruments for this process can be very different from each other. On the one hand, there are instruments and technologies which are tested in different scientific disciplines and are then applied into the study of cartographic heritage. The most exemplar technique is photogrammetry which is connected with cartography in many stages: first of all, the traditional process of map making using aerial survey data, but also in the new operations of non-contact digitization of historical maps. In the study of maps, the other relevant technologies are strictly derived from digital image processing such as radiometrical transformation of pixel content or the geometrical ones connected.
The first step in all the possible operations concerning historical maps, common to all processes, is digitization, the transposition of all contents from paper support to digital. Work experience shows that this operation is very difficult to standardize because every chart has its own physical, chemical and geometrical characteristics, so every map needs a specific, and well studied, digitization process.
This paper is to present the application of hardware and software elements to allow digitization of historical maps, characterized by deformation of paper support. There are many possible final products: for example digital representation of the deformation of paper support, but also orthophotos realized by the study of the smaller variations of paper surface.

1.1 Digitization

Today, establishment of a unique process of digitization of historical cartography seems to be very hard to solve because each map has its own specific characteristics which affect the choice of the most suitable process and instrument. In some cases the specificities are connected with the material support of maps, so they can be too sensitive in particular lighting settings or in special conservative condition. And also charts can be partially damaged and so they cannot be used. Finally the paper support can be too thick and maps become inaccessible

In the majority of these cases, digitization by planar scanner is not suitable to keep unchanged the characteristics of map.

The first process that can reply the traditional one, suggests the use of photogrammetry to survey and edit the geometrical, semantic and symbolic content of the chart. Final products are the traditional ones of photogrammetry: rectification of images in order to remove the effects of the projective transformation. Even if all the characteristics of paper are unchanged, this process doesn't give specific information about the deformation state of the support. So it is not possible to obtain some photogrammetrical elaborations such as orthophotos - really this operation can be realized by the use of two stereoscopic images, but it is very difficult to realize, above all for maps where there are few lines and big white part.

1.2 Digitization by laser scanner and digital camera

The process showed in this paper includes the possibility to also digitize maps with a highly deformed paper support. The fundamentals of this application can be traced back to the acquisition of the paper surface by laser scanning technologies and the use of a non-metric digital camera to recognize the pictorial aspect of maps

In particular, surface acquisition takes place by the use of a laser scanner, Handyscan by Creaform, which can be employed with just one hand and it gives as result a complete mesh of paper surface.

Instead digital camera gives the a description of the map and of its content

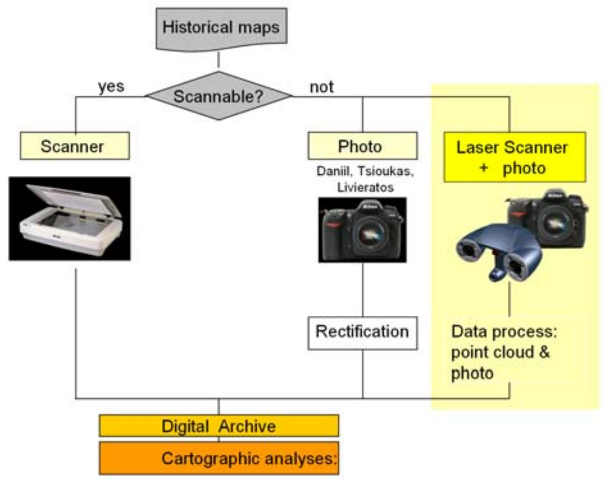

Figure 1: Different possibilities in the digitization of historical cartography.

2. SURFACE ACQUISITION

2.1 Handyscan.

The laser scanner used in this application is Handyscan, realized by Creaform, a Canadian Technological centre for reverse engineering and 3D digital solutions. For many reasons, this instrument is suitable for different applications. In this case, its most interesting characteristics are connected with the convenience and use in different environment conditions and for many aspects.

Because of its characteristics in the measurement field (Z precision to 0.05 mm and acquisition resolution to 0.1 mm), Handyscan has been classified as the third generation instrument of high resolution 3D scanners.

The laser scanner is composed of two cameras, eight lighting LED (four for each camera) and a laser tracker. It works like a triangulator instrument: the laser tracker projects a crosshair on the object and the two camera acquire the same time simultaneously, giving the spatial position of the point by the method of forward resection.

It was introduced as the first self-positioned hand-held scanner in the world. It doesn't need external information, because it uses a reference system realized by small reflective targets, with circular shape, in order to orient the single scans. After the initial acquisition of reflective targets, the software georeferences the subsequent scans using the grid of reflectors.

Finally this instrument can acquire objects of all dimensions, so there are virtually no limits in the dimension of maps to digitize.

Figure 2: handyscan

2.2 The acquisition stage

Even before dealing with the acquisition of the surface, it is necessary to set the reference system in a true way. Because of its design for rapid prototype or reverse engineering, reflective targets should be put in contact with the object to survey, with a relative distance between 2 and 10 cm, in connection to the complex shape and the final result to obtain. This operation can be done for other objects, but not with historical cartography, because it could happen to damage the map. So the reference system has to be materialized in a different way. In this case the purpose is to realize a 3D grid to put over the map (not in contact) and to stick the reflective targets on it. The use of the 3d grid of target and of a support plane, even signalized, allows a good 3D setters as reference system

After preparing the map and the 3D system of reflective targets, the instrument has to be calibrated either geometrically or radiometrically.

In the first stage, the aim is to use a control plate to check the relative orientation of the two cameras and to correct possible micro movements of the acquiring system

The scope of the second step of calibration, the radiometrical one, is to correctly set the photographic aspects such as the intensity of laser crosshair and the sensibility of camera sensors with regard to the different colours and number of symbols in the map.

Figure 3: 3D grid of reflective targets

The process goes on with the acquisition of target, so the set up of the reference system.
Finally, the scan of the paper surface. Before beginning, it is necessary to set the dimension of a volume-box which contains the whole object to scan. Then, the software makes it possible to acquire the surface using different resolution (high, medium or low) connected with the dimension of the reference voxel (dimension of voxel is about the distance between surveyed points).
In the end, the acquiring software provides few possibilities of data processing such as hole filling or small surface removal.
All data (target position, points on the surface and mesh) are recorded into the notebook connected with the scanner, and they can be exported using simple and widespread file format such a as STL and ASCII

2.3 Data processing

Acquired data can be processed by the software which have been used in the traditional handling of point clouds such as Rapidform, Geomagic (there is a specific plug-in for data acquiring in Raindrop software) or the usual 3D model software.
The resulting mesh is strictly organized in a regular network. From this, it is possible to obtain many representation of surface deformation such as a false colour image or a drawing by contour lines. In any event, it is first necessary to calculate the best fitting plane to find all the variations between the virtual plane and the real surface of paper. In the related examples contour lines are placed at a distance of 0.05 or 0.1 mm with regard to the amount of deformation.

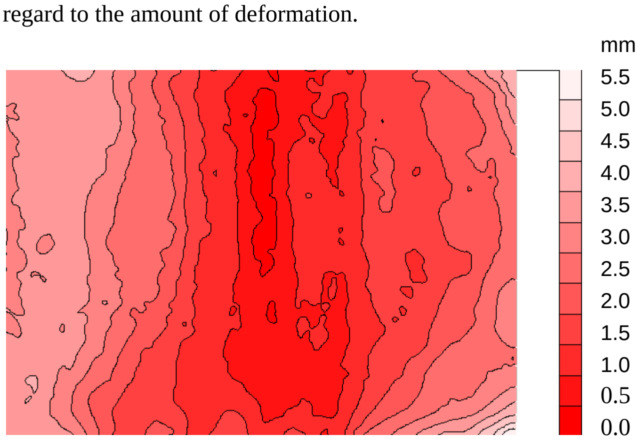

Figura 4: contour line representation of the deformation of paper surface

3. IMAGE ACQUISITION

The second step of digitization process is regarding the image acquisition of content of the map, by the use of a non-metric digital camera.
In these applications a Nikon D2X with a lens of 24 mm and a 12 Mpixel sensor, was used.

3.1 Image acquiring system

Because the 3D grid of targets is superimposed to the map, many steps are required to obtain a correct final result. The digital camera has to be installed on specific photographical device in order to take different images of the map but from the same position in space and with the same spatial orientation. In this way two images are acquired. Use of this device also guarantees the best lighting condition for image recording because it holds four spot lights which can be oriented in every direction.

Figura 5: The acquiring system: handyscan, notebook, digital camera, 3D grid and light device.

The first shot was taken by the camera with the 3D grid superimposed to the map in such a way to use reflective targets as control points and to estimate the orientation parameters of the photograph.
The second image was taken from the same position and orientated in a way to keep fixed the parameters, but removing the 3D grid. So in the second image the map is represented correctly without the presence of the grid. Since this image will be used to texture the DTM of the warped surface, the photograph has been acquired using Kodak color control patches to know exactly the radiometric content.
In the related examples, acquired images are characterized by pixels with a real dimension, on map surface, of 0,1 mm each one.

Figure 6: image 1 (above) to solve the orientation problem and image 2 (below) to realize the orthophoto.

3.2 Image processing

As mentioned, the first photo was used to estimate the orientation parameters. Since the digital camera is a non-metric one, the orientation problem cannot be solved in the traditional way, internal orientation and then relative and absolute one. This is why the operation was done using the Direct Linear Transformation – DLT – by using scanned targets as Ground Control Point. This makes it possible to reconstruct position and orientation of camera in the space.
At the end of the orientation process, the parameters were also used for the second image. It's possible to verify that position and orientation didn't change: considering the second image, points are in the same position of the first photo.

4. FINAL RESULTS

At the end of the photogrammetrical process, it's possible to realize the orthophoto that allows to represent the map in the orthogonal projection correctly. Obviously final dimension of pixel is connected with the initial dimension in the acquired image. Through the orthophoto, it's possible to have the correct representation of map, without the distorted effects due to the lens and to the deformation of support.
Like final result, the image content, orthophoto, can be fuse together with geometry of deformation to realize 3d representation where the deformation aspect is particularly evident.

5. EXAMPLES

Processes and techniques described in this paper have been applied to the digitization of some historical maps, collected and bound in books essentially.
The first attempts were applied to a collection of maps of the 18th century, bound in a book, which describe ports of the Mediterranean sea.
The effects of deformation are veru evident from the survey, and in particular the effect of binding, where there is a wave in the centre of the page.
In these examples contour lines represents a deformation of 0.1 mm each. Instead the orthophotos are characterized by pixel of a dimension of 0.1 mm each.

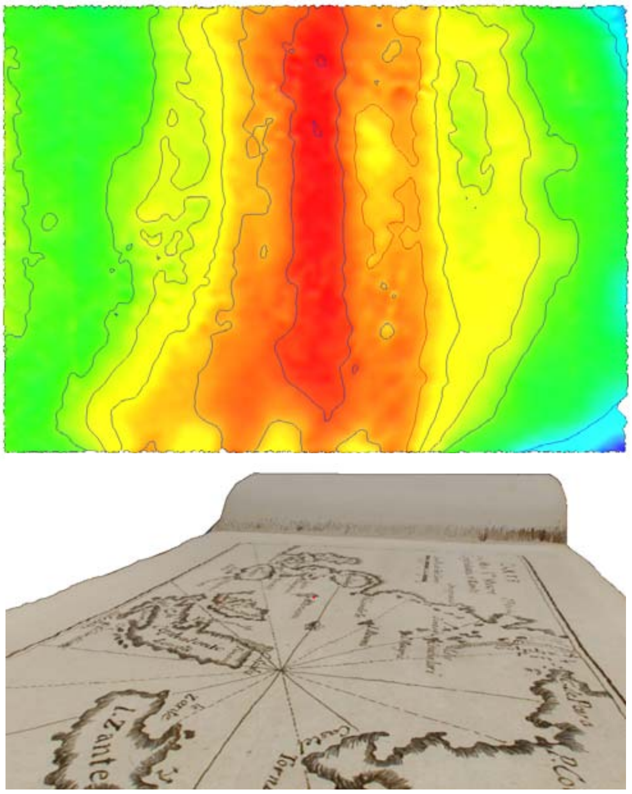

Figure 7: false colour representation of the support surface and perspective view of the textured surface.

In the second example, the process has been applied to the "Libro dei Globi" by Vincenzo Coronelli of 1702. In this book, he printed the gores which are necessary to cover the surface of the wood-globe used in 18th century. Every sheet is about 35 x 50 cm.

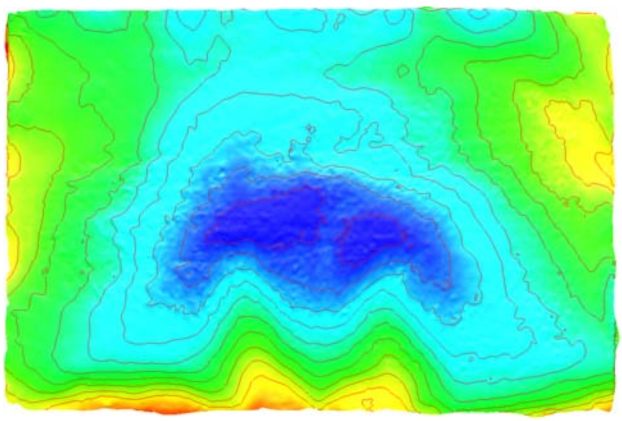

Figure 8: false colour representation of part of a fuse and final orthophoto

The test sheet was acquired using a Handyscan and digital camera to obtain the orthophoto of the map. Also in this case, the effects of the binding are clear directly from the false colour representation, and in particular the effect of two cords which "stretch" the whole paper

6. CONCLUSIONS

Even if it is not possible to set a unique and standardized process of digitization, however it is really necessary to go on the testing this application to deepen some aspects. First of all it is important to test the acquiring system in different condition and different objects as regards materials and geometries (rolled parchment, bound books or single sheets, but also deformed wall surfaces). Moreover, since the laser is classified as a second class instrument concerning the dangerous, it is necessary to verify the effect about the ink pigment of maps.
Another important aspect is connected with the possibility of exporting the acquired data (3D surface and the orthophoto, in a suitable format file such as an ASCII file which contains the coordinates X,Y, Z and radiometrical value RGB.
At the end, it will be useful to study also the data process stage in such a way to define the best filter to give the correct description of the surface, without losing some important information.
Another aspect of research is concerning the analysis and the characterization of deformations in the paper support, making a comparison between the deformed surface and the elastic membrane.

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