Vassilios Tsioukas[*], Miltiades Daniil[**]

3D digitization of Historical Maps

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Summary

Most of the modern maps around the world lie on paper subject or other flat but flexible material. Although, most of the historic maps in maplibraries' collections and museums are representations of the real world on paper there are still cases of

- anaglyph maps (3D maps),
- deformed maps (i.e. maps on books, atlases) that used to be flat originally and
- maps on wood, fabric, and other non flat material

All of the previous map representations certainly need to be digitized in the best possible and accurate method:

- for archiving purposes
- to provide their facsimile hardcopies
- for cartographic knowledge dissemination purposes

One way to provide the 3D model of the map's relief is by using conventional photogrammetric or scanning techniques (structure light or laser light scanning). In that way a 3D photorealistic object model can be acquired to give a "reading" accuracy and understanding of the map with an error smaller than the one the human eye can perceive.

Another aspect for the necessity of the creation of the 3D model of the map is the production of the unwrapped version of the relief/deformed map.

Most of the deformed historic maps were not undulated originally. Time and bad archiving conditions lead to their current deformation and through the digitization procedure an unwrapping process could be applied to provide a softcopy (and through printing a hardcopy also) of the original. In this paper a system and its accompanying software applications are presented that will help the creation of the 3D digital copies of deformed/anaglyph maps.

Introduction

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, "DIGIMAP-Discovering our Past World with Digitized Historical Maps" is the title of a recently funded project in EU and its main aim

[*] Assist. Professor at the Dept. of Architectural Engineering, The Democritus Univ. of Thrace, GREECE [vtsiouka@arch.duth.gr]

[**] Lecturer under contract at the Dept. of Architectural Engineering, The Democritus Univ. of Thrace, GREECE [mdaniil@arch.duth.gr]

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.

Current status

During the last decade certain limitations have placed major restrictions in the

- digitization
- archiving
- processing
- sharing through internet
- printing

of historical maps. Today, most of the above-mentioned limitations cease to exist due to the extreme evolution of computing systems and their peripherals (storing, printing, imaging and scanning devices) along with the reduction of their prices. Additionally, many commercial organizations have invested in developing devices and software to provide digital copies of objects and documents. Originally, most of the devices to provide digital copies of historical maps were scanners. However, the production of high resolution digital cameras has lead to the creation of camera based configurations and systems.
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).

Historical Map Digitization

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 rectified 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 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 lie 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. 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 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.

Our Approach

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. The process we follow in this paper's work is illustrated in Fig.1. The historical map is transformed into its digital form by the method of the digital photography, a non contact and harmless method. 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, then a number of overlapping 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. Then, we have to assure that the images must be taken in a vertical arrangement meaning that the photography axis is perpendicular to the map's surface. Our concept is to calculate and produce the Digital Surface Model (DSM) of every part of the map. Then the captured images are being corrected due to the distortions occurred by the surface undulations, a process similar to the orthophotograph production a well known technique in the Digital Photogrammetry discipline, and the final corrected orthoimages are draped onto the DSM. For this reason, is very important and a prerequisite demand, the map to be constantly positioned at the same horizontal level.

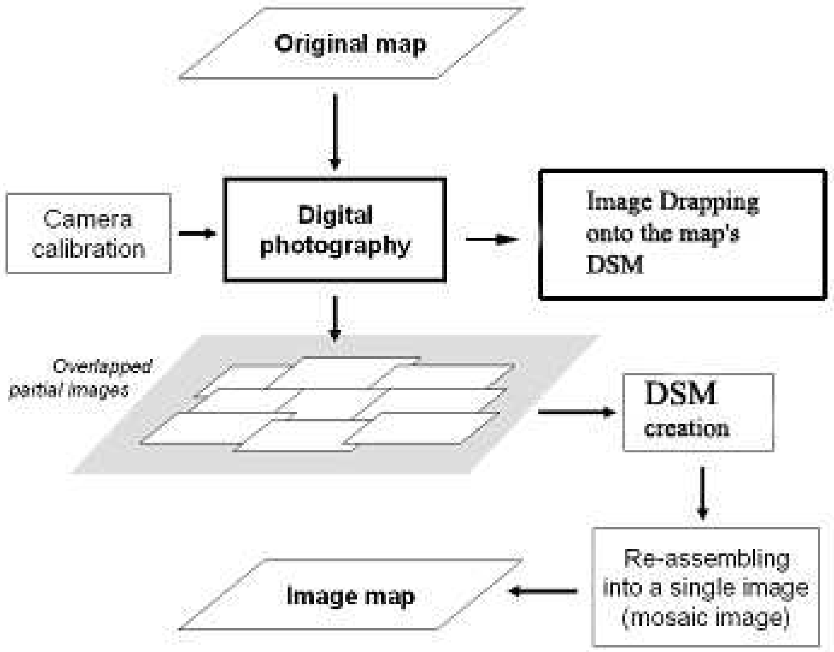

Fig.1. The flowchart of the transformation of the original map to its digital form and the necessary elaborations.

The system

In order to achieve the requirement for stereoscopic image capturing using a couple of similar cameras, we designed (Fig. 2a) and implemented a system (Fig. 2b) that allows to place and keep the analogue map at the same horizontal level and at the same time it pro-

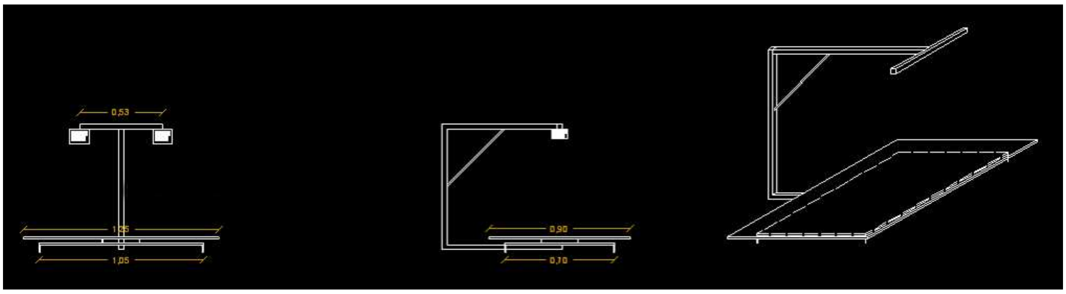

Fig. 2a. System design

Fig. 2b. …and implementation

vides the ability to move the map so that we can take overlapping stereo images. It also provides the ability to capture the digital images from different height, meeting thus the need to achieve the proper resolution of the images for the 1:1 scale reproduction. The system is a metallic-aluminum construction. Special prone was taken into account so that it should be as light as possible. Also the need for easy transport at the place where the map collection is located was taken into account in the way that it can be disassembled in two pieces. It consists of a large horizontal aluminum surface that carries the map. Its dimensions are 1.25x0.90m covering map dimensions as large as A0 size. The carrier is bolted on two linear guides that allow simultaneous or separate movements along the X and Y axes. On top of the map surface, in vertical direction one or two digital cameras can be positioned at adjustable height (fig. 2b). The suspended cameras can be fixed to a horizontal baseline that is also bolted on a linear guide moving vertically and in this way the maximum height they can reach is 1.5m. The maximum baseline distance can be up to 53cm. Simultaneous remote image capture from the two cameras is allowed by using proper designed software. This setup is very flexible for the handling of the map to be photographed and it also allows a good estimation of the cameras' position in space.

By calculating the cameras' position and attitude (elements of the cameras' exterior orientation) the generation of the digital surface model of the map is achieved. In order to calculate the exterior orientation parameters but also and the calibration parameters of the two cameras, special control point field should be imaged and measured. Towards this direction a 3D LEGO® cubes construction was built and measured in the best accurate way (fig. 3). The Digital Surface Model of the map is provided after a matching process between interest (high in texture) points found in one of the images of the historical map and matched to its conjugate. Additionally, the epipolar geometry leads to a set of constrains to detect possible blunders and perform an error free model (Fig. 4).

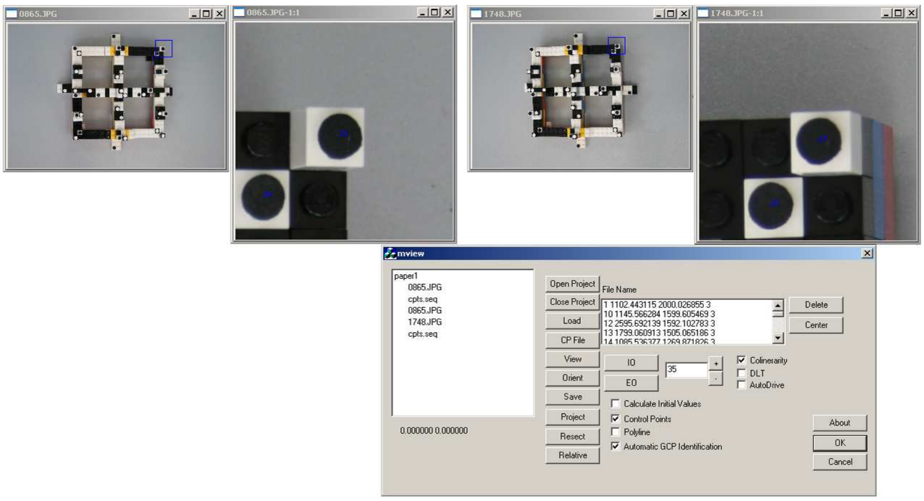

Fig. 3. Control points' field image collected for the determination of the calibration and the exterior orientation parameters

Every stereoscopic model leads to the creation of an error free DSM that is independent from all the rest. By generating the orthoimages from every DSM a photorealistic 3D model of the map can be created that will lead to the final orthomosaic by applying a matching procedures between subsequent ortho images.

Example

In the following example a deformed version of a scanned copy of a historical map has

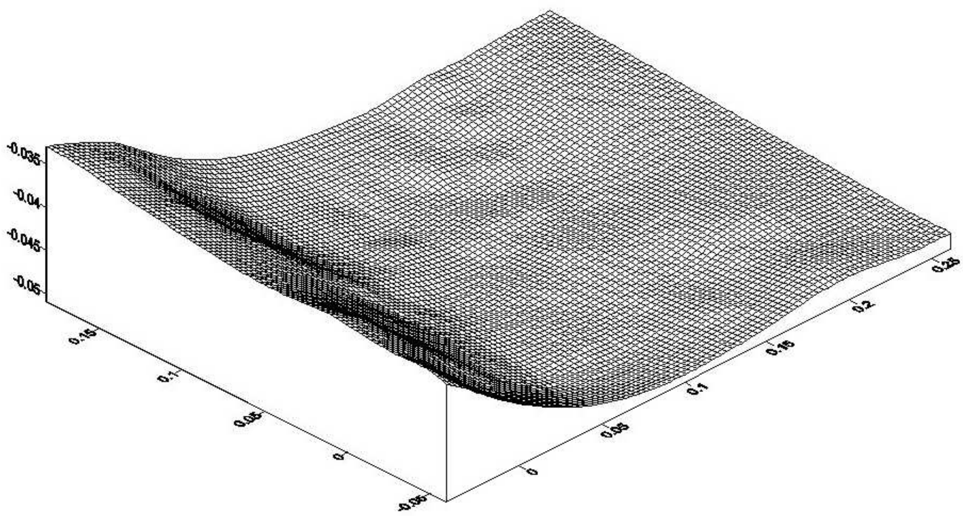

Fig.4. DSM of a single stereoscopic model

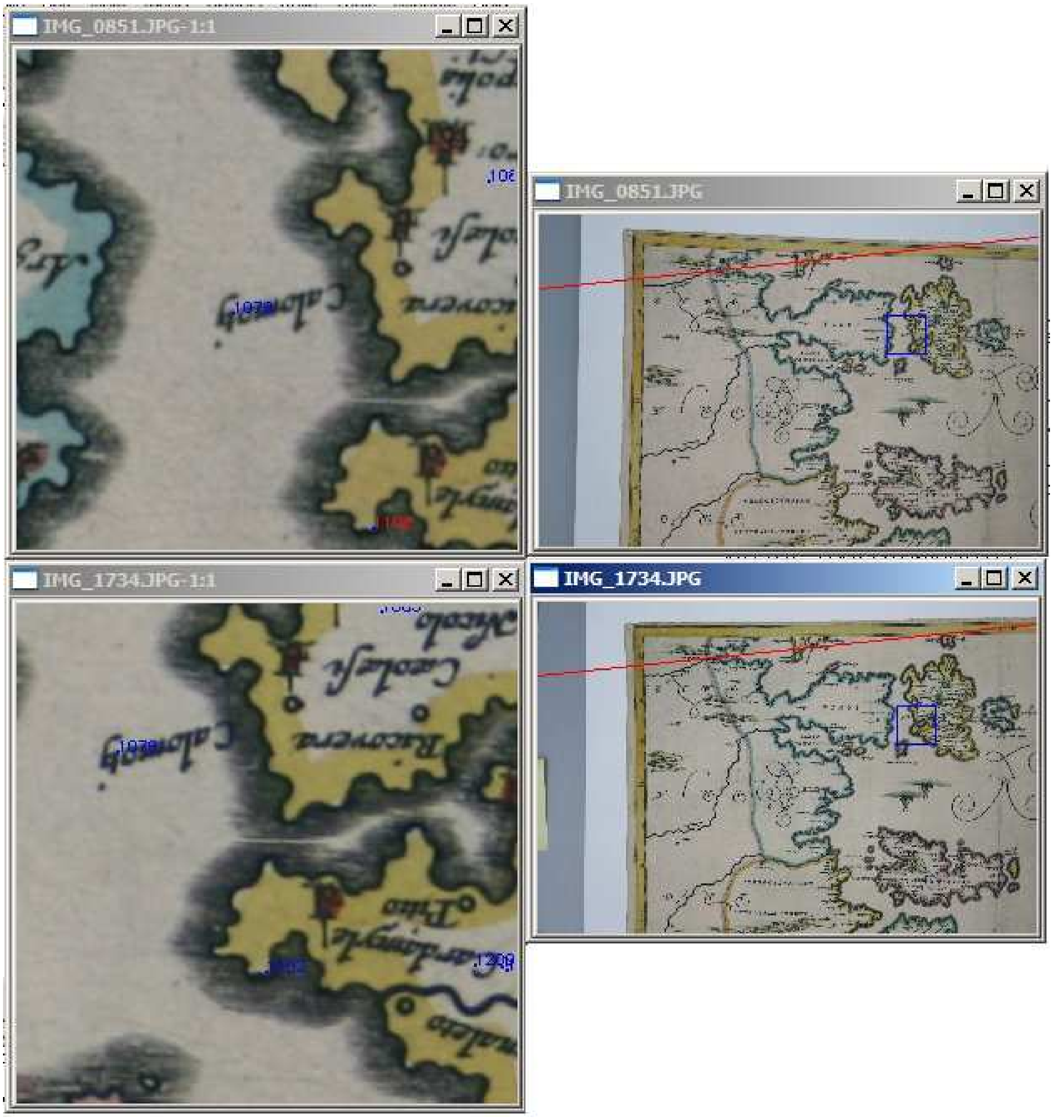

Fig. 5. Matching process. The red labeled point has been extracted from the DSM generation as a bad match according to the epipolar geometry constrain.

been processed in our system to generate the 3D model of the map and the overall ortho-mosaic. Some parts of the map suffer from great relief that extend almost 1.5cm from the lowest level of the map. However, the matching process lead to an error free model (fig.4) by constraining the solution with the epipolar geometry (fig.5). Finally, an overall ortho-mosaic is created that may be examined in 3D (Fig. 6).

Future research

In the near future our research attempts will be directed to the implementation of an algorithm that will produce the unwrapping version of the historical map. All of the above mentioned algorithmic steps and procedures will be integrated in a single windows software application. Special care will be taken to provide an easy to use interface so that any novice user can operate the software and generate the 3D digital copies of historical maps.

Conclusion

In this paper an approach has been made to implement a method to digitize in the most accurate way historical maps. The major aspects taken into account are:

- The accuracy should be more than 80μm
- The system's setup should be inexpensive and portable
- Most of the procedures to procedure the overall map should be performed automatically

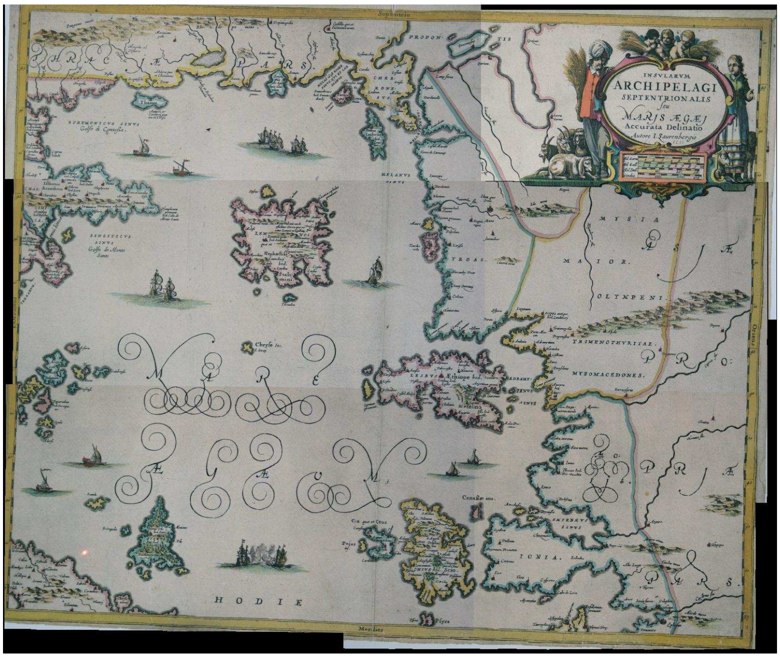

Fig.6. Final orthomosaic. No bending has been applied, on purpose, in order to distinguish the separate tiles of partial orthoimages.

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