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Possibilities and problems in close range non-contact 1:1 digitization of antique maps

Keywords: Cartographic heritage; digitization of old maps; non-contact 1:1 digitization; harmless digitization; close range photogrammetry.

Summary

The issues raised from the photographic close range, non-contact and harmless digitization of antique maps are discussed in this paper, concerning the production of 1:1 scale digital copies of antique map originals, using partial digital images as taken by low cost non specialized digital cameras, available in the general market. A proper implementation technique is described and the technical requirements and specifications, that are important for the relevant photogrammetric processing and camera calibration, are analyzed in order to obtain the most precise digital copies of historical maps.

Introduction

The transformation of antique[1] maps in digital form is, in some cases, a requirement in the domain of *Cartographic Heritage,* this new trend in modern cartographic culture and thinking (Livieratos 1999, Livieratos and Myridis 1999). It is also one of the main terms of reference of the newly established ICA working group on digital technologies in cartographic heritage[2]. The process usually followed, for the transformation of antique maps in digital form, is the line-wise scanning of the original map either by *contact* scanning or by *non-contact* scanning methods. The first is a relatively low-cost process suitable to originals which are not vulnerable in any mechanical and/or chemical alterations of the supporting material and of the drawing, due to the contact scanning and illumination. The second is a high-cost process which is, in principle, less risky than the contact scanning, at least as the mechanical alterations of the map original are concerned, checking, of course, the impact of the illumination during the scanning[3]. In any case, both scanning methods are not totally harmless especially when the original is suffering vulnerability to alterations. On the other hand, the advantage of the scanning methods is that the digital copy is derived at the same scale as the original, obtaining thus, 1:1 digital copies of the originals, considering of course some geometric alterations induced into the digital image by the scanning source geometry, which should be corrected.

Photography is another way of getting digital images of antique map originals. It is a non-contact technique and is done either directly, through digital photography, or indirectly by digitizing the slides available from the globally used documentation of antique maps on this traditional analogi-

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[1] Here, the term ‘antique map’ is referred to any map belonging to the domain of cartographic heritage and is, in general, vulnerable (in any sense) to contact digitization.

[2] Established by the International Cartographic Association in Summer 2005, see web.auth.gr/xeee/ica-heritage

[3] Some non-contact scanners are equipped with low intensity illumination.

cal photographic medium. In the photographic case, the transformation of the antique map originals in digital form is totally harmless but, on the other hand, the digital image result suffers distortions mainly due to the central projection inherent in photography and due to the imperfectness of the camera lenses. Another shortcoming in this approach is that, in most cases, the scale, 1:k, of the digital copies that are obtained photographically, is less that 1:1 (k>1) especially when the originals are in certain dimensions, or when non-specialized and non-high cost regular cameras are used. In Fig. 1, the alternative flow for the transformation of antique maps in digital form, by scanning and photographic techniques, is schematically shown.

In this paper which is focused on digital photography, the relevant discussion brings forward the ideas and proposals on the digitization of antique maps as exposed for the first time few years ago (Daniil et al 2003). In that previous work the concept for a LCOR digitization of old maps (Low Cost with Optimal Response) was introduced and analysed in detail. Here, following the LCOR concept, the main problems raised by the introduction of non-contact 1:1 close-range photographic digitization, are analysed. These problems are countered and have to be solved in order to derive an appropriate photographic digital image copy, the closest possible to the original map concerning:

a) The scale,
b) the geometry,
c) the radiometric properties.

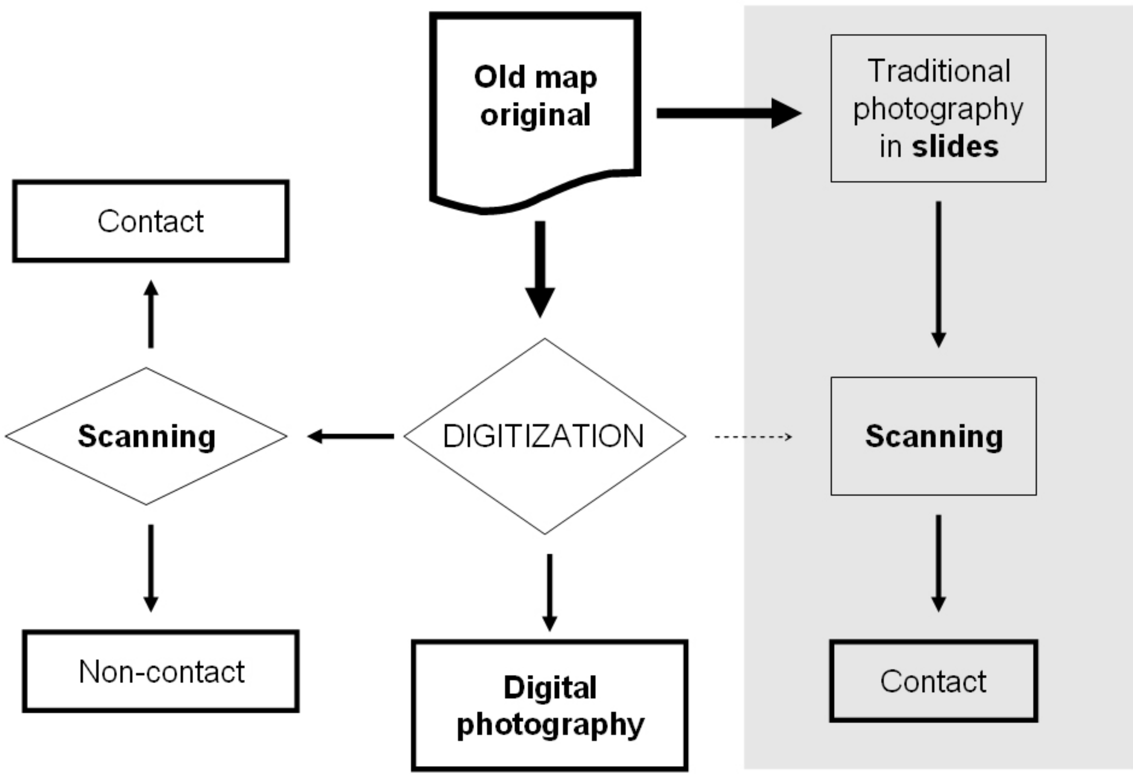

Figure 1. Alternative options for antique map digitization.

The whole approach is based on some basic requirements of LCOR digitizing concerning the logistics of the issue, i.e. low costs for the instrumentation in use (non-professional digital cameras and lenses widely available in the general market) and for the software implemented in the processing, using mainly home-made and/or low cost algorithms also widely available in the market.

The proposed digitization process is addressed mainly to map collectors and map curators who dispose valuable maps and wish to file their collection in digital facsimile form, optimally close to the originals, without risking harms in scanning, keeping at the same time the digitization costs low and avoiding time consuming and technically charging digitization.

Description of the process

The process followed in this study is illustrated in Fig. 2. The antique map is harmlessly transformed in digital form according to the non-contact method of digital photography. Since the main concern is to fulfil the requirement for a 1:1 (facsimile) digital copy, in the case the dimensions of the original do not allow a single photo-take fulfilling this scale requirement, then a number of close-range overlapping photographs are taken.

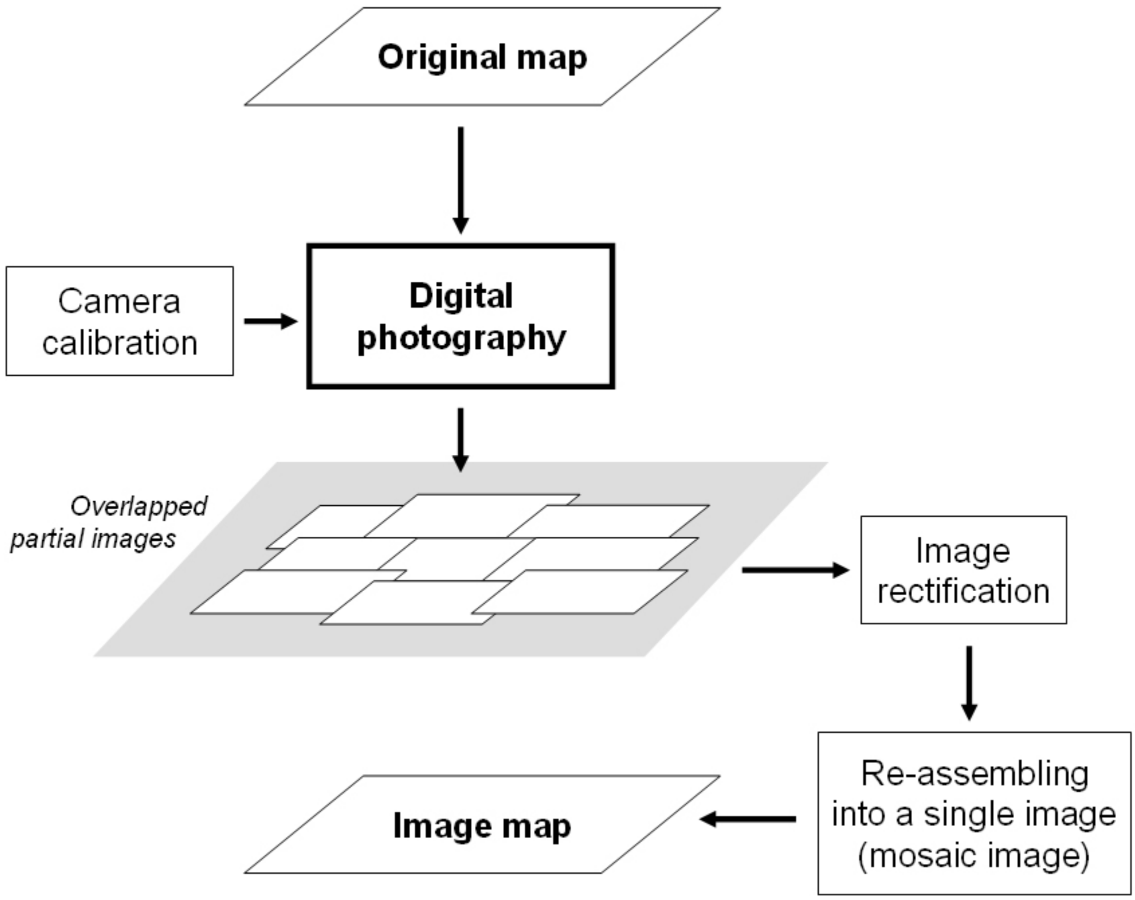

Figure 2. The transformation of the original map in digital form by digital photography.

The shooting distance should be the proper for a 1:1 final copy, which means that the raw photographs should be generally taken in larger scale. This, of course, depends upon the digital camera's specifications (resolution, lens type) which are rather permissive today in the majority of 1 K€ level products. Another constrain is the requirement for orthogonal photograph take, which means that when the photography axis is vertical the map should be in horizontal position and vice-versa. Finally, adequate and uniform illumination should be available during the session of photographic takes.

The next step is to resolve a series of problems associated to the rectification of the images taken by digital photography in order to transform the central projection, induced by photography, into orthogonal projection (orthophoto / ortho-image). In this step, the elimination of distortions induced by lens optics is also considered. In this class of problems the main concern is for:

a) The implementation and (automatic) extraction of control points that are necessary for the calculation of central projection parameters (or any other mathematical model) and hence the creation of the rectified product, and
b) The calibration of the digital camera or the use of a generic polynomial model representing the way the digital images are created.

The last step is the final 'assembling' of the corrected images into one single image, according to an image mosaic-technique. The major concern here is that, the final image should satisfy the 300dpi resolution requirement, which is the optimal figure for a high quality printed facsimile of the original map. Other secondary problems that might occur during the digitization process can be easily solved or neglected due to their insignificant effect in the final product.

The technique for digital rectification

In this study, it is followed, in general lines, the procedure which is successfully used in architectural photogrammetry (see e.g. Dallas 1996: 283, Grussenmeyer, Hanke, and Streilein 2002) according to which low relief facades are rectified using conventional surveying methods to implement reference control points that are necessary in order to define the relation between the surface of the camera sensor and the vertical planar facades. The process is straightforward and in a fraction of time a rectified ortho-projection of the facade can be generated. In many cases a single shot is not enough to provide the single ortho-rectified image of the buildings facade and overlapping images are taken covering the whole facade. The overlapped images (tile images) are then rectified one by one and merged properly to the single final image of the whole.

Here, the images of an old map were taken with the use of a 1 K€ level digital camera in order to create either (directly) a 1:1 single rectification image of the historical map or (indirectly) an ortho-mosaic image coming from the proper merging of a number of overlapping images.

The marking of control points on the original map surface is not generally feasible for obvious reasons. For the realization of the horizontal control that is important for a monoscopic photogrammetric processing and for the digital rectification of the map image, a lightweight Plexiglas plate is used. The transparent plate is forcing the map to take its horizontal position (when this is possible without harming the original) letting the light passing through it and allowing the phototake of digital images. Once the proper photography distance is defined, the position of the camera should be fixed. The image capturing can be realized using an automated mechanism (infrared triggering or remote capturing through USB connection and specialized software).

The initial image is coming from a high-resolution printed sheet of reference control points (RCP) that is placed below the transparent plate used to keep the original map in horizontal position. The sheet with RCP refers to a dense grid of circular targets (determined with great accuracy) that can be automatically collected using a simple best fitting ellipse algorithm. The correspondence of RCP and their image location on the digital image is able to provide, through the central projection mathematical model (or any other proper mathematical model), the appropriate parameters needed to rectify not only the image of the grid of RCP but also of any other image that is taken from the same camera position, above the transparent plate, which can then host beneath any part of the original map.

Geometric analysis of the rectified image

The minimum resolution of the taken images (hence the corresponding pixel size in the original map surface) is the parameter that defines the appropriate distance between the camera and the surface of the original map. The characteristics of the camera lenses (camera constant and lens radial distortions) are also defining part of the geometric analysis, therefore the distance between the camera and the surface of the original map.

The pixel size of the final digital image should be less than 80 microns in order to obtain the required 300 dpi in the final image copy, as stated previously. When the original map is of small dimensions, the image capturing of a single shot could be enough only when 80 microns pixel size is achieved. For a 6 Mpixel digital camera, the potential maximum dimensions of a map to be digitized should be less than 3.72X2.5 cm. But this size is not common in the history of maps, where the map sizes are generally larger. For a map size of about 50X70 cm the digital image should have pixel dimensions of at least 6250X8750, which means a capacity of 54 Mpixels. At this moment no camera available in the general market, in a reasonable and affordable price, reaches this ultra high resolution requirement. For this reason, a number of overlapping (of at least 20% overlap) rectified images should be used, capable to provide the minimum required resolution of the 300 dpi. The image tiles, output of the rectification process of the image shots are then merged into a single mosaic image. The rectification process is following the method described above for every single image tile. The original map to be copied and the RCP sheet can move freely along the *x* and *y* axes below the fixed camera in a way to ensure the levelling constrain and a necessary number of overlapping images are thus obtained enjoying the same geometric properties as the initial image of the RCP sheet.

Mosaic imaging problems and calibration

The conclusion of the process is to generate the unique mosaic image from the rectified tile images. One might think that this is a trivial and easy to handle work. However, some problems, like e.g. the radial distortion of the lens and the eventual shallow undulations on the map surface (Fig. 3) may lead to the adoption of rather unusual photogrammetric solutions in order the rectify the images.

The calibration of the lens is applied before the operational use of the camera and is a standard procedure in every photogrammetric project. It is used to eliminate the radial distortion errors that tend to transpose the image points to the image centre. The result of the calibration is the derivation of radial distortion parameters in specific camera settings. The camera constant should be fixed with no focusing since focusing changes the camera constant. In the case of self-calibration, various camera settings are accepted but only one during the whole image capturing session. The parameters which model the lens radial distortion are embedded in the co-linearity equations, in the case of stereoscopic photogrammetric processing, and provide finally an error free 3D model of photographed objects.

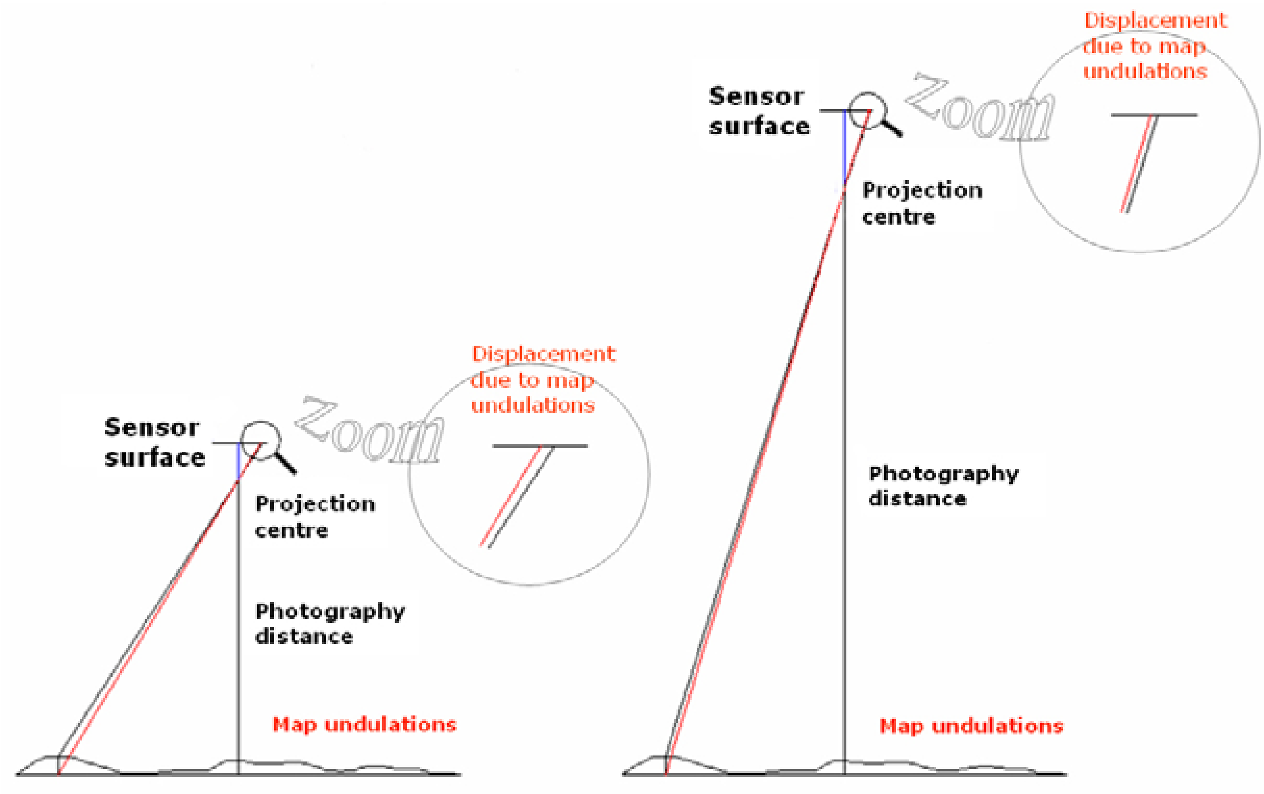

Figure 3. Displacements on the surface of the sensor due to shallow undulations on map surface.
The camera constant and its distance from the object, influence the displacements.

In a typical photogrammetric process there is no need to correct for radial distortions since the output product is either a Digital Elevation Model or a vector map, which both are radial distortion free. Even when an ortho-image is created, the radial distortion errors are encountered in the production process and the final image is distortion free. However, in the case of a digital rectification the geometric model of the central projection does not embed parameters for radial distortion correction. In this case the images suffer great deformations due to the low quality of the commercial lenses mounted on mass production digital cameras.

Another problem that impedes the precise merging of the rectified tile images is the presence of even shallow undulations on the surface of the old map. This shortcoming is greater when the camera constant is small (Fig. 3). The displacement of the image points is preventing the creation of a perfect mosaic image and small gaps and discontinuities occur in the overlapping regions of the tiles (Fig. 4a). A typical calibration process requires:

a) fixed camera constant, and
b) no focusing.

However, in the case of our application, the absence of focusing gives blurred images and fixed camera constant is not at all easy to get since most of the digital cameras available in the general market are offered with varying lenses.

In order to minimize the deformation of the image points due to map undulations, we used an intermediate camera constant. According to this strategy, the camera constant remains unchanged during the image capturing session with the use of focusing for clean imaging.

In our case, the camera pre-calibration is not applicable. Also, self-calibration is not possible when monoscopic photogrammetric processing is followed. Similar to self-calibration is the embedding of distortion parameters in the central projection model. According to our experience, a generic model that may give a solution for the image geometry, but also a very satisfactory approximation of the radial distortion parameters, is a 3rd order generic polynomial associating the image point coordinates with the RCP coordinates. This model can provide a rectified image whose residual errors, after the merging process, is less than the pixel size. In this way an accepted mosaic image is generated.

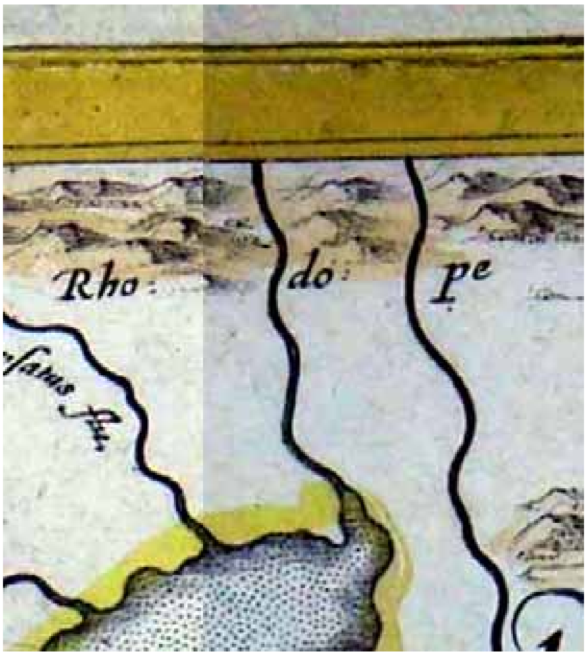

Figure 4a. The seam line between different rectified image tiles is apparent when the central projection model is used.

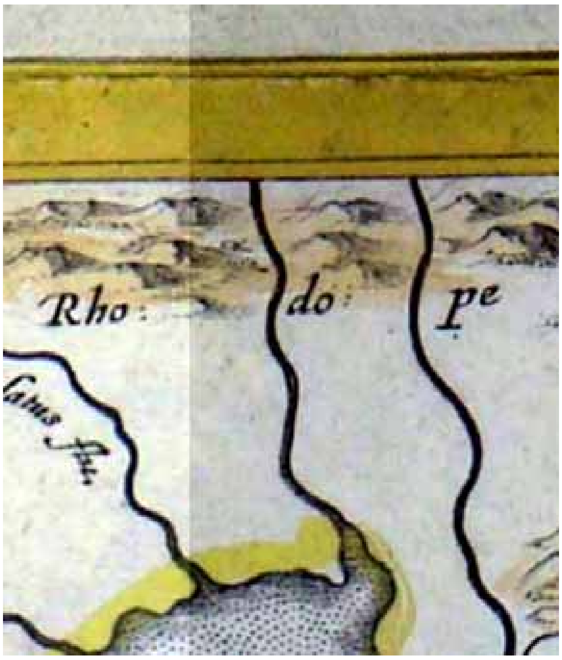

Figure 4b. The seam line is not visible when the rectification of the image is carried out using a 3rd order polynomial.

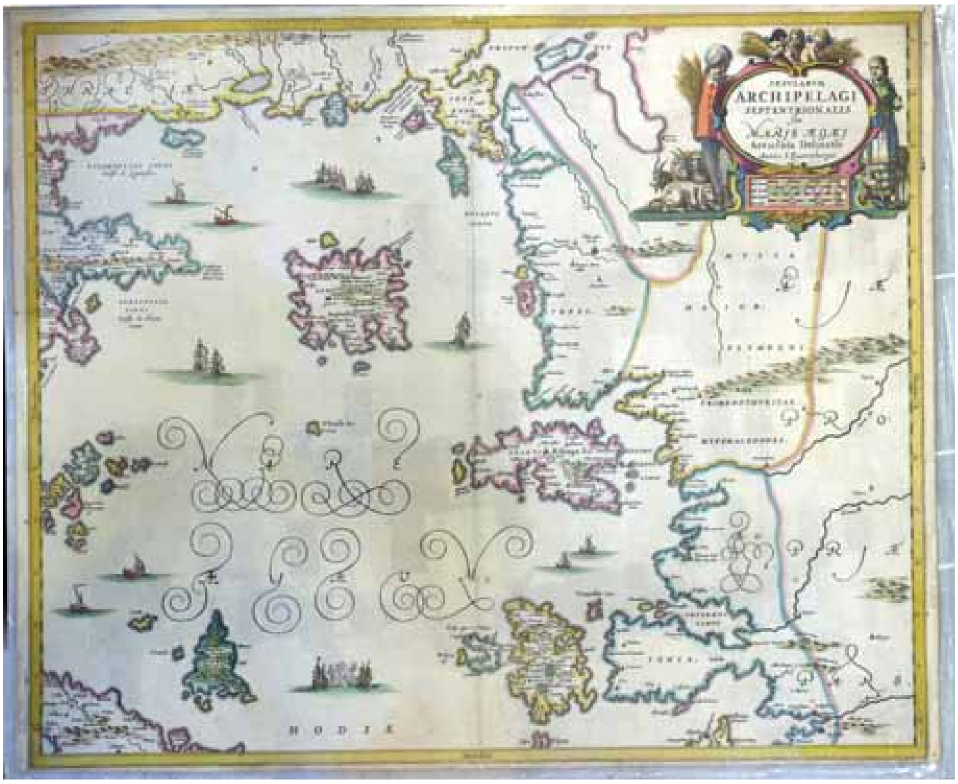

Figure 5. The final rectified 1:1 mosaic image of an original 17th century map.

The final step, for the creation of the mosaic image, is the use of software for assembling the rectified image tiles in a single final image. This type of software, which is also applying the necessary radiometric corrections on the tile images before the assembling, is available free of charge in the general market when a digital camera is purchased. In this study, the 1 K€ level Nikon 8700 digital camera has been used with the associated ArcSoft Panorama Maker software application for the assembling of the tile images. The software puts automatically the seam line between the images, applying also image blending for an optimal mosaic image (Fig. 4b, Fig.5).
In order to check the validity of the process described above, the final resulted image (Fig.5) was evaluated with the use of another digital copy of the map original used in this study. This digital copy coming from a different scanning source of digitization (the regular contact type of scanning), which was possible in the case of the specific old map used (with estimated low risk harm), was then adjusted to absorb geometric alterations (mainly in size) and was compared with the use of the image processing technique of *digital transparency* (Daniil 2006). The results were very assuring and promising for the quality of the non-contact photographically taken map image copy, of the order of the point graphic tolerance (0,2 mm).

Conclusions

In this paper we illustrated a new low cost, rapid to implement and easy to handle approach for the LCOR production of 1:1 digital copies of antique map originals, in 300 dpi (best for facsimile printing) using the harmless non-contact technique of close range digital photography. Our aim is to provide a consistent method for an easy and well-documented process for harmless facsimile digitization of antique maps that can be applied not only by experts, but also by persons who are not familiar with modern technologies or do not possess consistent budget for highly specialized instrumentation and digitization applications, targeting mainly to the medium and small size collections with limited financial resources. The cost of the required hardware and software is very low since general digital cameras, of any format, can be used together with home made software for the digital rectification process and with software for the mosaic imaging which is given free with the camera acquisition. The LCOR concept for the digitization is fully satisfied in this approach.
This method can be used not only for the digitization of antique maps but also for any other antique textual and/or graphic document on paper or any other material, like fabric or planar wood surfaces, that need 1:1 harmless and reliable reproduction, when scanning is not possible or permissible.
Future research is focused on the creation of the 3D model of antique map surfaces and the creation of ortho-images using conventional stereoscopic photogrammetric processing in a highly automated, low cost and easy to handle mode. The continuous reduction of costs in the market of digital cameras in association with the development of higher resolution imaging sensors is the promising preamble for such type of approaches which help the generalization and the spreading of the idea for harmless 1:1 digitization of old maps.

Acknowledgement

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