

# PHOTOGRAMMETRIC REPRODUCTION OF THE MAP OF MEXICO 1550

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## ABSTRACT:

The aim of our research is to develop a method for producing 3D high-resolution photogrammetric reproductions of historical maps. As an example we have created a reproduction of the Map of Mexico from year 1550. It is one of the oldest extant maps of the Tenochtitlan, the ancient capital of the Aztec Empire, which was located on the site of present day Mexico City. The size of the map is 114 cm x 78 cm and it is painted on parchment, which has been curved during the years. Researchers are interested in the map because of the legends they could interpret from its texts and detailed pictures. The map is however out of reach in a closed glass cabinet in the University of Uppsala, Sweden. The requirements for the reproduction were that the curved surface of the parchment is taken into account and the resolution of the texture should be so good that also the little details of the map are distinguished. We created the reproduction using similar photogrammetric techniques as in terrain mapping, though the used camera and the implementation of measurement coordinate system were different than in traditional terrestrial projects. The most important advantage of the photogrammetric approach is the possibility to create accurate reproductions, which can be examined with high magnification.

## 1. INTRODUCTION

Printed and material facsimiles of historical and archival artifacts are frequently used by scholars for research, as valid replacement for working with the original. For reasons of security and preservation, facsimiles are also routinely used in exhibitions by museums and libraries. Because of their value and rarity, printed facsimiles are usually also exhibited in glass containers, where they are out of the reach of the public unable to peruse its contents. In contrast, researchers and audiences frequently raise questions about both the accuracy and consistency of digital artifacts, with regards to their material counterparts.

In spite of the fact that digitalization could solve many problems regarding access to rare and unique archival materials, traditional image scanning techniques do not properly address many of the needs and issues of museums and libraries that also happen to be major research centers. For one, these methods cannot accurately transfer radiometric and volumetric properties of archival items made of organic materials, such as parchment and vellum (Brown, 1994) and which through the passage of time have acquired an almost three dimensional topography. A sizable amount of archival artifacts in European libraries belong to this category of parchment items.

As used in this project, the concept denotes a digital representation of the original object of such a high quality, in terms of resolution, color and shape accuracy, that it is accepted by researchers who would normally require to get access to the material version of the object. This is a significant feature that distinguishes the proposed solution from other “postcard” or “videogame” quality solutions, which are mainly intended for non-expert audiences and experiential purposes. This latter option makes it possible to develop diverse types of digital cultural heritage artifacts

targeted to different audiences. The intensive data acquisition strategy presupposed for such a product could also ensure that there will be enough for future generation products.

Digital facsimiles offer significant benefits: They can protect the original from excessive use, make the material available in the best possible quality to the widest audience and provide the option of reconfiguration and augmentation. The facsimile can be made a part of new works.

In this paper we describe a process of creating a digital reproduction of the Map of Mexico from year 1550. The project is led by Dr. Lily Diaz-Kommonen from the University of Art and Design Helsinki, Media Lab. Other collaborators are the Helsinki University of Technology, Institute of Photogrammetry and Remote Sensing and the University of Uppsala’s Carolina Rediviva Library.

At the Helsinki University of Technology we have been developing a method for producing 3D high-resolution photogrammetric reproductions of historical maps. The most important advantage of the photogrammetric approach is the possibility to create accurate reproductions, which can be examined with high magnification. The reproduction of the Map of Mexico was created using similar photogrammetric techniques as in terrain mapping. Because the used camera and implementation of the coordinate system were different than in traditional terrestrial projects it was interesting to see how these techniques work.

## 2. THE MAP OF MEXICO

The Map of Mexico 1550, also known as the Uppsala Map because it is kept at the Uppsala University Library, is one of

the greatest existing historical documents recording the early colonial history of Mexico. The map is thought to be the work of the noted Spanish cosmographer Alonso de Santa Cruz. It is also one of only two known maps that give a fairly accurate picture of the ancient city of Mexico-Tenochtitlan and its surrounding regions in the mid 16<sup>th</sup> century. (Díaz-Kommonen)

The clearly drawn roads over the mountains to other parts of the country permit us to retrace the routes taken by the Spanish conquerors. The map also gives information about the ethnography and the flora and fauna of the region. The population is shown performing a variety of activities, such as woodcutting, canoeing, hunting, and fishing. The approximately 150 glyphs on the map, representing human and animal heads, feet, hands, circles and stars, refer to name places. (Larsson, 2002)

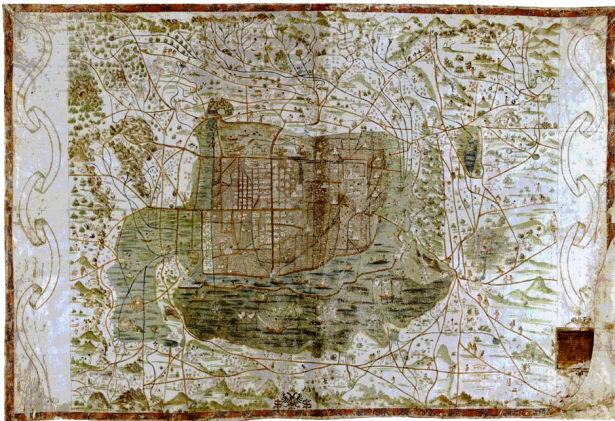


Figure 1. The Map of Mexico

The dimensions of the document are 114 cm lengthwise and 78 cm widthwise. Though no conclusive analysis of the material properties of the artifact has been done, expert opinion indicates that the inscriptions may have been painted using pigments on a surface comprising two sheets parchment joined in the center. (León-Portilla, 1986) In time the parchment surface has curved and acquired a three dimensional topography.

### 3. REPRODUCTION OF THE MAP

The requirements for the reproduction were that the curved surface of the parchment is taken into account and the resolution of the texture should be so high that also the smallest details of the map are distinguished.

#### 3.1 Image acquisition

The original map was photographed in the University of Uppsala, Sweden. Prof. Henrik Haggrén from Helsinki University of Technology was developing a method for photographing maps and Dr. Lily Díaz-Kommonen and photographer Antti Huittinen from the University of Art and Design Helsinki took the photographs.

In order to get enough detailed images, the map had to be photographed in pieces. The scale of the photographs was designed to be 1:2. In this scale the smallest details of the map can be distinguished. The used camera was a Sinar repro camera with a 180 mm macro Sinacron objective. The image

size of the camera is 10 cm x 12,5 cm, so the map was photographed in pieces of 20 cm x 25 cm.

The photographs were taken through a grid frame, with grid size of 20 cm x 25 cm. The grid was made of thin threads and formed four strips, each strip consisting of six images. Each grid cell was covered with an image size of 4" x 5", color diapositive (100 ASA Kodak Ektachrome EPP, f/22.5) and 9 cm x 12 cm, black and white negative. The distance between the camera and the surface of the map was about 66 cm. The grid was lifted a few centimeters up from the map so that the whole surface of the map was visible in the photographs. The grid was used here both for guiding the photography and for controlling the geometry between adjacent images.

Because the surface of the map was curved, an elevation model was needed for producing an image mosaic. Therefore each strip was recorded with a stereo photography of 55 % overlap. In order to provide "normal" stereo viewing of the map as well, an additional stereo mate was recorded for each image covering a full cell area. The base length was 22 mm and the base-to-distance ratio was 1/30. This corresponds to a normal stereo viewing at a distance of two meters. One additional set of b/w-images was recorded with low oblique lighting in order to produce relief effects by shadowing. In total 80 color images and 124 black and white images were taken. (Haggrén)

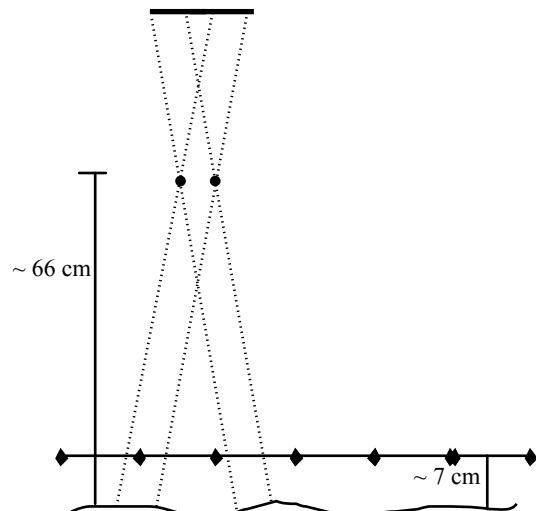


Figure 2. The map was photographed in pieces through a grid frame.

Images were scanned with pixel size 1200 dpi or 20 µm. Assuming that people normally see points having a size of 0.1 mm, the scanned images could be viewed with five times magnification.

When we got the scanned images it came out that the edges of the images were cut off. It is obvious that this was a mistake because the corners of the images would be needed for defining the interior orientation of the images. Despite of that we decided to use the images for the reproduction.





Figure 3. A color image of 20 cm x 25 cm size area. The gridlines are visible in the edges of the image.

### 3.2 Orientation of images

Totally 24 images and their 28 stereo pairs with overlap of 55% were oriented to one block with Pictran software. These images were colored except two black and white images, which had to be used because the corresponding color images were missing. The resolution of the images were scaled half of the original size, to pixel size of 40  $\mu\text{m}$ , so that the orientation process would not become too heavy.

**3.2.1 Interior Orientation:** Because the edges of the images were cut off, the exact coordinates of the principal points could not be defined. In this case even the estimate that the principal points would be in the center of the images was not very accurate because some edges were cut more than the others and all the images were also of different size. That is why we defined initial coordinates of the principal points to be (0,0) and let the value be a free variable in block orientation. We didn't either know other internal camera parameters than the focal length and they were thus zero.

**3.2.2 Block Orientation:** All the 52 images were oriented to one block. The gridlines, which were visible in all the images, were used as control information (Figure 4). Totally 5 xyz control points and 4 z control points were measured to the edges and to the center of the image block. Also 527 unknown tie points were measured manually from the images. The standard deviation of image coordinates was 0.68 pixels.

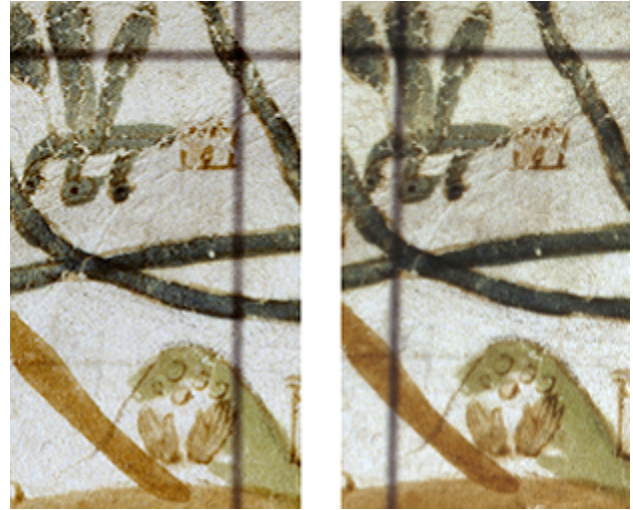


Figure 4. The gridline intersections were used as control information. Because the grid was lifted a few centimetres up from the map surface, the intersection appears to be a little bit different places on different images. The size of these pieces is about 2,0 cm x 3,5 cm and the same area can be seen in the upper right corner of the figure 3.

### 3.3 Digital elevation model

Geomatica OrthoEngine software was used for generating a digital elevation model (DEM) of the map. First the original images (pixel size 20  $\mu\text{m}$ ) were resampled to epipolar images. Then the elevation models were extracted automatically from the overlapping epipolar pairs. The pieces of extracted elevation models were geocoded and combined automatically together to form one big mosaic DEM. In the areas where adjacent DEM pieces had overlap, the average value of elevation was used.

After combination there were some visible edges left in the seam areas of the adjacent DEM pieces. They were bounded and filtered with a smoothing algorithm. The pixel size of the final DEM is 2 mm and it includes 219 000 points. The elevation varies within 2 cm.

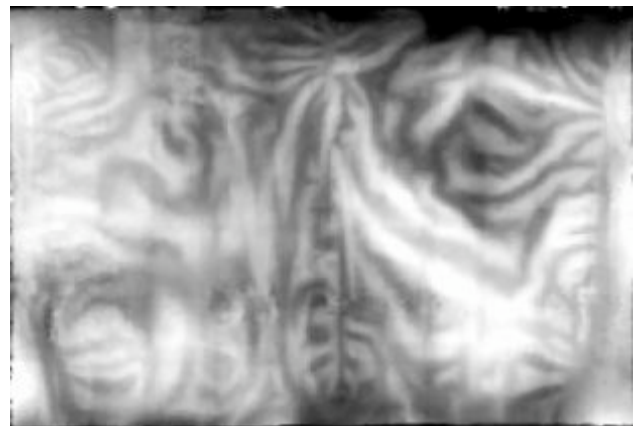


Figure 5: The digital elevation model of the Map of Mexico. Lighter areas are higher than dark areas.

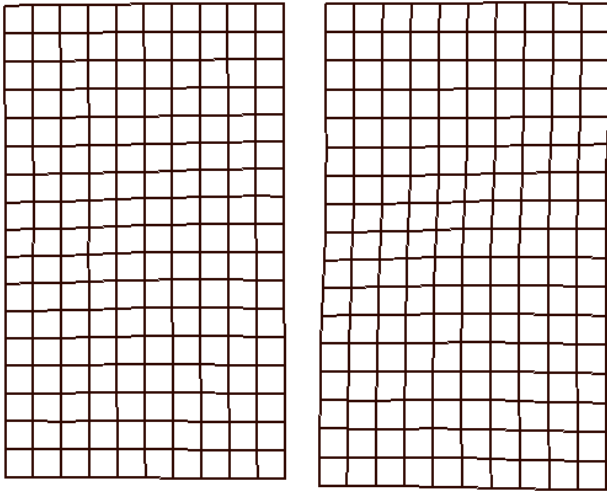


Figure 6: These 2 mm DEM grids are from the same area that can be seen in figure 4. Curvature of the surface is visible.

### 3.4 Image mosaic

The image mosaic was created with software using 25 color images with about 5% overlap. The gridlines, which were visible in the edges of the images, were bounded off so that they would not be visible in the mosaic. The images were orthorectified using the digital elevation model. The cut lines between the images were selected to be the edge features and the color balance to be adjusted in the overlapping areas of adjacent images. The orthorectified geocoded images were then automatically joined to the image mosaic. The images seemed to fit well together and the mosaic looked seamless.

The resolution of the mosaic we produced first was 0.1 mm although the images were scanned with pixel size of 20  $\mu\text{m}$ . The full resolution mosaic would have been too heavy to be handled in our computers (over 2 Gb). If the best resolution is used, an image pyramid for multi resolution representation should be created.

### 3.5 Triangular network

A triangular network with point spacing of 4 mm was created. Coordinates of digital elevation model were exported to ImageStation Stereo Display software and triangulated. The image mosaic was draped over the network. As a result we got a textured 3D surface model, which can be rotated and examined from different angles.

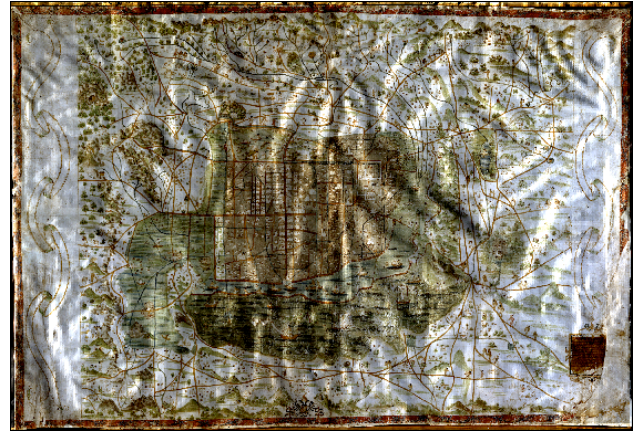


Figure 7. Image mosaic draped over the triangular network. The curved surface of the map is visible.

### 3.6 Stereo mosaic

The image mosaic was converted to stereo pairs to be viewed both in digital stereo workstation as well as an anaglyph image. Stereo pairs were created using the digital elevation model. First the DEM was converted to left and right side DEMs shifting the pixels to left or right in proportion to elevation. In other words the x-coordinates were changed in proportion to z-coordinates. We used proportions  $\pm 3/10$  and  $\pm 6/10$ . The bigger the shift of x-coordinate is the more the stereoscopic effect is emphasized. The new coordinate values were interpolated to equidistant points to form the new left and right side DEMs. These DEMs were used to create new left and right side ortho images from the original images. The new ortho images were merged to new left and right side image mosaics from which the anaglyph version was composed.

## 4. DISCUSSION AND CONCLUSIONS

The photogrammetric reproduction of the Map of Mexico was created using similar techniques as in terrain mapping. In general these techniques worked well and the developed procedure is usable for creating accurate reproductions of maps.

However in our project the interior orientation has need for improvement. Because the edges of the images were cut off the principal points could not be defined. We didn't either know the other camera parameters than the focal length. In order to produce accurate reproduction, camera calibration and use of original image format is crucial.

The poorly defined interior orientation as well as possible errors in control information affects the block geometry. This could be seen as edges in the digital elevation model. The edges are still slightly visible in the seam areas of adjacent DEM pieces, though the average values of elevations were used in the overlapping areas, when the pieces of DEM were merged and the edges were filtered with a smoothing algorithm.

The full resolution digital reproduction of the Map of Mexico (pixel size 20  $\mu\text{m}$ ) is planned to be shown in exhibitions as 3D surface model or as anaglyph images. The user interface will be interactive so that the users can get a close view into the details and have a feeling of touching the

map. The digital reproduction gives an experience of being in front of a high-resolution image of the map.

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