Electronic Restoration: Eliminating the Ravages of Time on Historical Maps

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Abstract. Geographic and mathematic analyses of historical maps require highly accurate adjustments to manuscripts in order to eliminate distortions caused by time and use. Earlier proposals for electronic restoration only offered effective solutions when compensating for tightly bound or straightly creased books. Applying a different solution, we have encountered a way of electronically restoring the map to its original shape, producing not only a more beautiful map, but also one suitable for further geographical analyses.

Keywords: Electronic restoration, digital preservation, digital archives and museums, historical maps, geographic analysis, and mathematic analysis.

Time and nature have not been kind to many of the world's most important and beautiful historical maps. Stored either folded or tightly rolled, maps can be damaged by being opened, examined, and then stored. Edges fray along the folds, or the curled map refuses to lay flat. Exposure to rain, seawater or moisture in any form causes the previously flat surface of maps to ripple, distorting the flat face of the original drawing into a series of peaks and depressions. Surviving charts thus contain characteristics that significantly distort the original drawing or engraving.

In an era of digital photography, high-end digital back scanners or cameras can capture the image of the original and transform the paper or vellum into pixels. With wavy and damaged maps, photographers most often electronically eliminate distortion with editing software such as Photoshop because maps are usually scanned or photographed for purposes of illustration. Editing out the ripples and tears transforms the map into an appealing image for presentation in books, postcards, publicity brochures, and calendars. However eye-catching these images seem, they remain useless beyond their visual impact.

However, in the last ten years a digital revolution has occurred in map-making. Highly sophisticated geographic software such as ArcGIS, and ERDAS Imagine has replaced pen and paper as the basic tool for constructing and analyzing maps in many countries around the globe.

More can be accomplished with digital images of maps than ever before. For example, census and voting information can be overlaid on maps to discover how groups of people voted, and locations of crimes can be plotted to help police find the perpetrators.

E.A. Fox et al. (Eds.): ICADL 2005, LNCS 3815, pp. 100 – 108, 2005.

While images produced for illustration obviously cannot be used for geographic analysis, the original unretouched digital images can be employed. However, without taking the ripples, folds, and frayings upon the map into account, any resulting analysis is flawed. Eliminating the distortions caused by time and nature remain essential to answering important geographical questions.

With such digital corrections we could begin to answer previously asked but irresolvable questions: the accuracy of scales, uniformity of measures of distance, and the type of projection or underlying model upon which early cartographers drew their maps. Since Mediterranean nautical charts marked the first stages in the development of modern scientific cartography, we considered rectifying these maps crucial to understanding how mathematical and geometrical construction of maps unfolded between the thirteenth and sixteenth centuries when Mercator drew his now famous world map. As a result we considered medieval and early modern maps one of the more important artifacts to restore electronically as well as one of the most technically challenging.

Because no library would allow its patrons or conservators to physically alter the map by steaming or taping it together, the process of correcting the ravages of time has to be accomplished electronically.

Others have proposed useful techniques for modifying digital images or scans to compensate for shadows in too-tightly bound books or paper that has been creased in a single vertical line. [1] However, all these methods of correction rely upon industrially manufactured rectangles that define the sheet of paper or page of a book. Rectifying distortion of pre-industrial books and papers remains a different task. Medieval vellum and early modern paper rarely form perfect geometric shapes; somewhat flawed, misaligned sheets prevail. Damage on these surfaces also often presents itself as oddly shaped waves or curves.

Maurizio Pilu still proposed a process for altering warped documents, but his corrected images remained far too flawed to be suitable for the additional mathematical analyses needed to answer questions about early map-making. [2] We agree with Pilu that a polygonal mesh (such as the one shown in Fig. 6) constitutes the best geometric starting point for correction, but we drew upon a different procedure to create a mesh and applied other mathematical formulae to rectify present-day distortions. In short, to subject historical maps to newer sophisticated analyses, we needed to restore the maps to the condition in which they were originally created.

The basic principle of the triangular mesh has been introduced into cartography (for adjusting contemporary maps) under the rubric of "rubber sheeting," so called for its virtual stretching of the underlying image. Both of the major map-making software packages, ArcGIS and ERDAS Imagine utilize a mesh as the foundation of their transformation of maps. While designed for contemporary maps, both tools could potentially electronically restore historical maps to their original condition. Both software programs employ the same mathematical formula (polynomial transformations) to the digital mesh in order to adjust a digital image into a known coordinate system, but they do so differently. Of the two, however, ERDAS Imagine's method proved to be more useful for historical maps because it can adjust to multiple misshapements.

Maps become distorted or destroyed in different parts or sections. Thus, the right hand edge of a map may have frayed, or water may have damaged the center left region. One corner of a map may have ripples while another corner does not. Put in other terms, distortions in historical charts are locally distributed. However one of the software packages, and the most widely used, ArcGIS turned out to be unsuitable for digital refurbishment. Even if you chose control points in just a small damaged area of the map, ArcGIS' technique distributes the error over all of the map's pixels, thus changing even those areas that have remained in their original (undamaged) condition. Thus this process introduces error in the already correct portions of the map even as it attempts to fix the error in a small region.

The other major software package, ERDAS Imagine, not only allows us to correct each of the damaged areas of the map separately, but also it keeps the undamaged sections of the map in their original form. (In geometric and mathematical terms, ERDAS Imagine's referencing tool constructs a local polynomial transformation by employing a triangular-based network generated using the nearest contiguous three points.) Employing the nearest three points to construct a triangle eliminates the problems that Pilu encountered in constructing the mesh. Using ERDAS Imagine we were able to select the damaged area to transform while leaving the unharmed areas intact. The resulting map is as beautiful as the retouched digital image, but has the additional advantage of being closer to the original.

If reconstructing a medieval map in the Mediterranean coastline tradition were as simple as applying ERDAS Imagine's procedures to create the triangular mesh, we would simply refer readers to the appropriate pages in ERDAS Imagine's manual [3] along with a few simple instructions on using general control points. Unfortunately, other issues complicate this process.

The foundation of this kind of map - as of every chart in this Mediterranean tradition - is a circle with thirty-two spokes or rhumbs, each corresponding to a sailing ship's direction. Research on several of these coastline charts in the British Library using microscopes and magnifying glasses confirmed that the rhumb lines of the compass were laid down first, and the map then drawn on top of them. [3] Therefore the underlying grid to which we would adjust the maps is not the more familiar right-angled grid, but rather a series of compass roses.

To illustrate the electronic restoration process, we chose an important historical map, Jorge de Aguiar's 1492 drawing of the entire coastline of Western Europe, the Mediterranean, and Africa almost to the Equator. The first large dated map to cover such an immense territory (including Portuguese voyages down the coast of Africa to the Equator), this map resides in the Rare Book Collection of Yale University. Like many older maps, it has suffered damage over the centuries. Drawn on vellum, the map

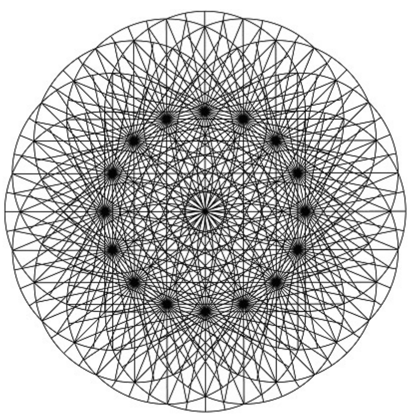

Fig. 1. Rosette generated using CAD software

Fig. 2A. Original map loaded into Viewer 1

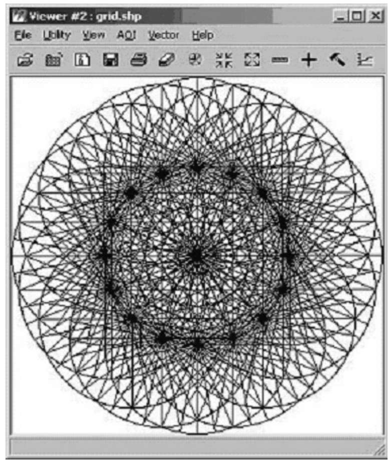

Fig. 2B. Rosette loaded into Viewer 2

Fig. 2C. Options in the raster image viewer

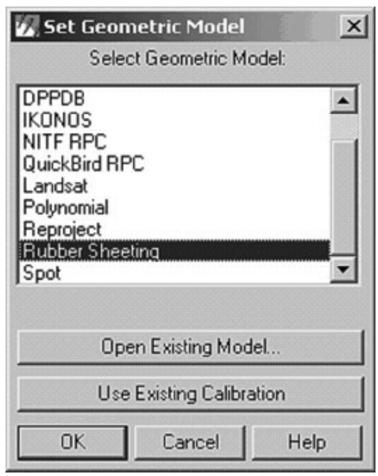

Fig. 2D. Geometric models dialog box

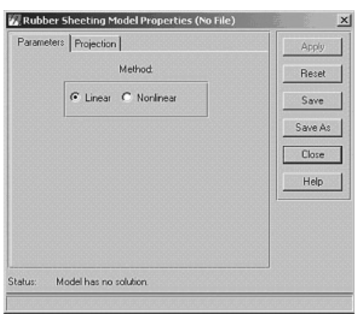

Fig. 2E. Rubber sheeting model parameters dialog box has a significant rip at the bottom along a crucial part of the African coast. Exposure to rain, seawater or some form of moisture caused the previously flat surface of vellum to ripple. Aguiar's chart contains several wavy areas in different areas along the coastline.

Before beginning the digital restoration, we needed to precisely identify the construction pattern of the grid. In the Aguiar map, the map's foundation is a circle with lines radiating every 11.25 degrees. This circle is systematically repeated every 22.5 degrees generating a rosette shaped structure. Using AutoCAD, a Computer Aided Design (CAD) software, we were able to create a circuit of compass roses that corresponded to every rhumb line drawn upon the chart (Fig. 1). This rosette became our reference, the structure to which we would adjust the wavy and torn sections of the Aguiar map.

To start the restoration, we opened two "classic" viewers in ERDAS Imagine, one with the distorted original map and the other with the structural rosette. In the first viewer, we added the image of the nautical chart as a raster layer (Fig. 2A). In the second viewer, we loaded the rosette as a vector layer (Fig. 2B). Under the raster image viewer, we selected geometric correction (Fig. 2C). A dialog box appeared and we selected rubber sheeting from the menu (Fig. 2D). Under the parameters title, we were faced with two choices, linear and non-linear. After multiple transformations using both the linear and the non-linear method, we did not note any significant difference between linear and non-linear transformation options in the rubber sheeting dialog box. Therefore we selected linear transformation.

Under the Projection title (Fig. 3A) we selected Set Projection from GCP Tool, and a Ground Control Points (GCP) Tool Reference Setup dialog box appeared asking us to define the underlying framework that we would use to adjust the map (Fig. 3B).

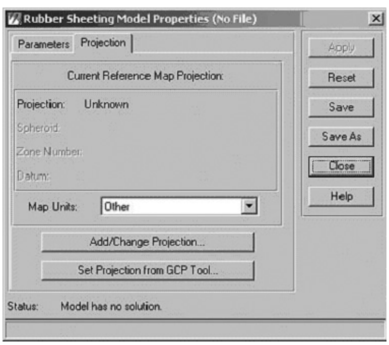

Fig. 3A. Rubber sheeting model properties

Fig. 3B. Ground Control Points (GCP) Tool Reference Setup dialog box

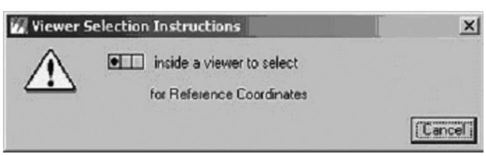

Fig. 3C. Viewer Selection Instructions dialog box

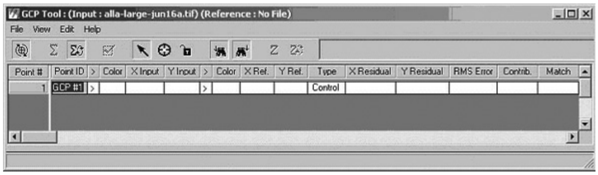

Fig. 4A. Ground control point tools table

Fig. 4B. Chip extraction viewer from Viewer 1

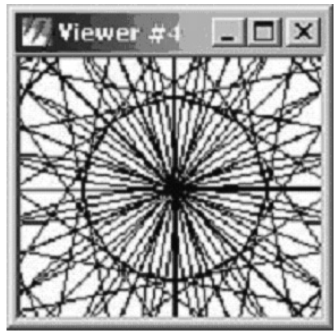

Fig. 4C. Chip extraction viewer from Viewer 2

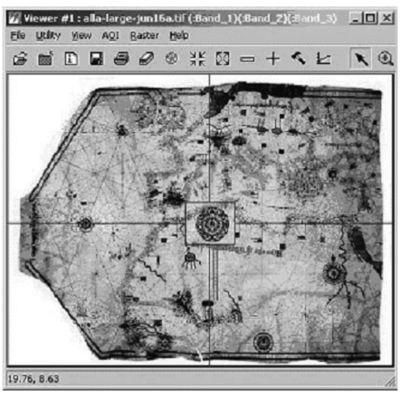

Fig. 4D. Selector box in Viewer 1

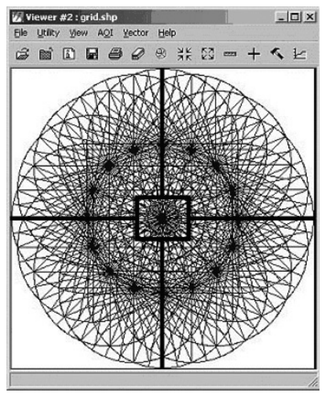

Fig. 4E. Selector box in Viewer 2

Since we already had the structural rosette in another window, we selected "Existing Viewer" by clicking on the viewer. A dialog box containing a table of input and reference data points (Fig. 4A) emerged at the bottom of the screen and two smaller viewers, viewer 3 (Fig. 4B) and Viewer 4 (Fig. 4C) appeared in addition to the two viewers containing the original image and the compass circuit. The selector box was dragged across the map image in Viewer 1 (Fig. 4D) and the corresponding selector box pulled across the rosette in Viewer 2 (Fig. 4E). The contents of the selector box Viewer 3 and Viewer 4 respectively displayed the close-up image of the area inside each of the two selector boxes. Using the rhumb lines as a guide, we aligned the selector boxes in each of the viewers so that they corresponded to the same areas.

We were then ready to begin the geometric correction.

The next step began the precise identification of common points in the map image and their equivalent in the structural rosette. These points commonly called Control Points link a place on an unreferenced image to a location on a structure with coordinates, in our example the lines of the rose. The next and most delicate step of the process involved creating data points first in Viewer 1 (Fig. 4D), and the corresponding location in Viewer 2 (Fig. 4E), by a mouse click. For each of the damaged areas we chose a set of three or four control points that included all of the damaged section.

We repeated the process, identifying each of the damaged sections on the map and linking them to the underlying compass rose circuit. With a large image as complex as the Aguiar map, we created three hundred such separate points, with the image appearing as it does in Figures 5A and B.

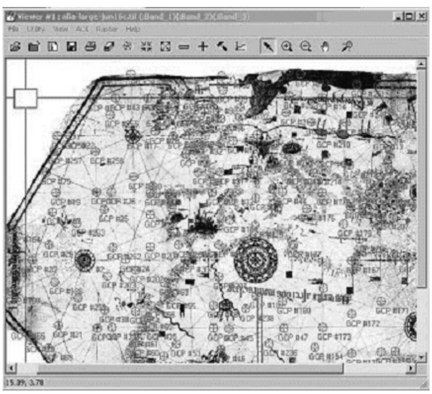

Fig. 5A Selected Ground Control Points (GCP) in the raster viewer

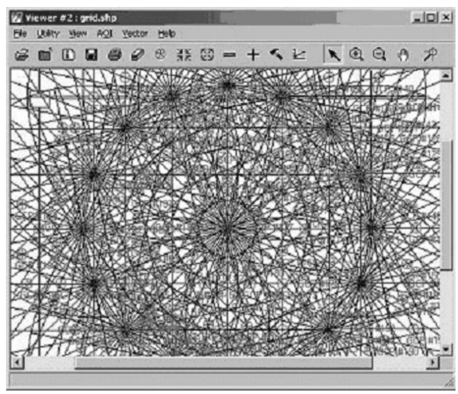

Fig. 5B. Selected Ground Control Points (GCP) in the vector viewer

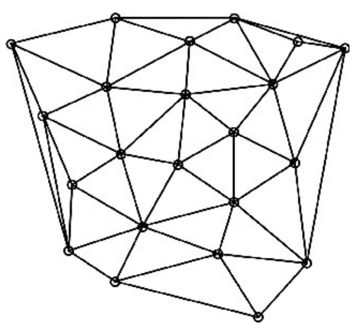

Fig. 6. Triangular Mesh

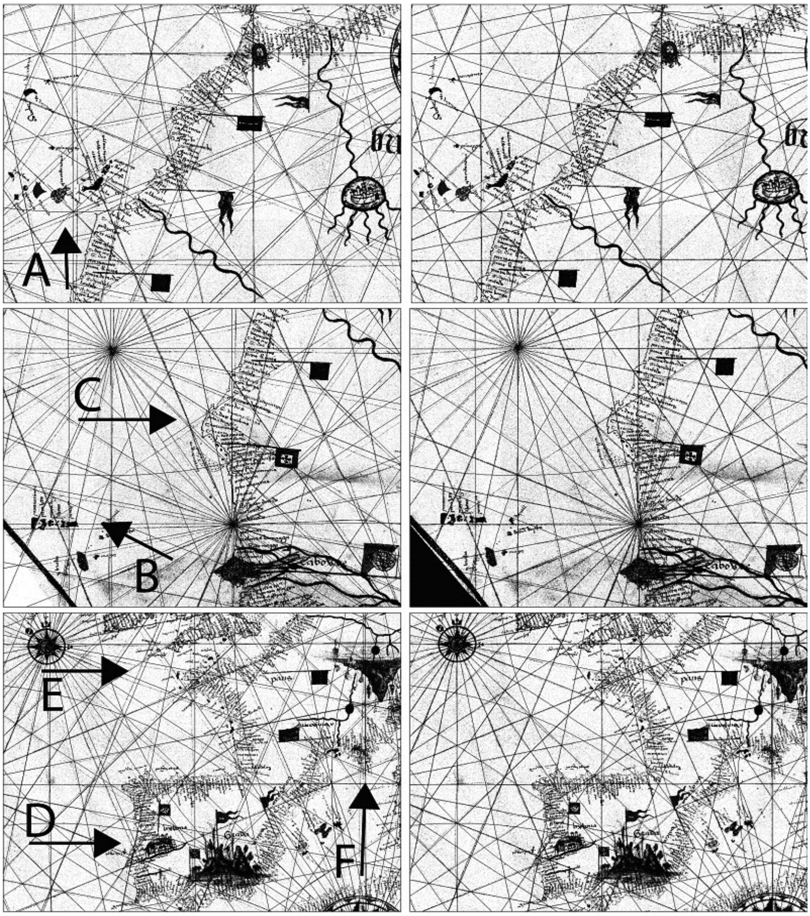

Fig. 7. Comparison between the original map (left) and the rectified (right)

Once we had control points distributed over the separate damaged sections, by pressing the calculation button, the computer began a process of taking the list control points and joining them into a mesh of triangles (Fig. 6), ERDAS Imagine uses the Delaunay Triangulation that creates the most equiangular triangles--those without any other point inside. Having created this mesh, the computer then solved a first order polynomial equation system in each triangle using the polynomials:

$$x' = a_0 + a_1 x + a_2 y \quad (1)$$

$$y' = b_0 + b_1 x + b_2 y \quad (2)$$

Where x' and y' refer to the coordinates in the original image, x and y to the coordinates in the rosette, and a_0, a_1, a_2, b_0, b_1, and b_2 are the Unknown values. To solve an n-order transformation, the computer requires a minimum of (n+1)(n+2))/2 points; in the case of the first order, the minimum of points are three (the ones in each triangle). Therefore, the problem is reduced to solving a system of six equations with six unknown values.

To go from the equation to a corrected image, we clicked in the multicolored square icon in a window on the screen labeled "Geo Correction." ERDAS Imagine's rubber sheeting tool then adjusted each pixel in the original (damaged) image using the solved equations and saved the adjusted pixels as a new file.

We compared the newly restored image to the original to see what changes the transformation had made. The easiest changes to detect visually are those in the alignment of the compass rose itself. In the damaged images, the compass rose lines are irregular, often located a considerable distance away from where they were originally drawn. On the corrected map, we can see how the spokes radiating from the center of the compass line up almost perfectly with the foundational compass rose.

To ensure that the rubber sheeting correctly transformed the map, we imported the original image, the corrected image, and the rosette into ArcGIS as separate layers. Next we georeferenced each of the separate layers using the first order transformation option. This option only rotates, rescales and moves the images, allowing us to align the images with the grid without distorting them.

In addition seeing realignment of the spokes of the compass wheel, the georeferenced map shows that many apparent errors on the map actually resulted from subsequent damage. Indeed the electronically restored version demonstrates a map far more accurate than first suspected. (Fig. 7) Aguiar drew the Canary Islands closer to where they actually lie relative to the African coast (near Cape Juby) (A). Other locations drawn more accurately include: the Cape Verde Islands (B) and Cape Blanc (C) in the North Atlantic coast of Africa, the Atlantic Coast of Portugal and Spain (D), the English Channel between England and France (E), and Hyeres Islands off the Mediterranean coast of France (F). The electronic refurbishment of the map allows us to appreciate the talent of this fifteenth century map-maker, but improved understanding of cartographic techniques is only one benefit of this technique.

The advantage of undertaking such restorations should not be lost on conservators and rare manuscript librarians. By having an electronic version of the map available for use by scholars, libraries could prevent further wear and tear generated by the same packing and unpacking process that damaged the original. In addition, libraries would be able to supply researchers with an electronic version of their rarest maps that are suitable for further geographic analyses.

Acknowledgements

Joseph Kellner, layout and Sarah Billington, research.

References

1. Brown, M. S. et al, "Document Restoration Using 3D Shape", *Int'l Conference on Computer Vision (ICCV'01)*, Vancouver, July 2001.
2. Pilu, M. "Undoing Paper Curl Distortion Using Applicable Surfaces", *Computer Vision and Pattern Recognition (CVPR'01)*, Hawaii, December 2001.
3. "Chapter 6: Polynomial Rectification" *ERDAS Imagine Tour Guides v8.5*. Atlanta, GA: 2001. 135-150.
4. Campbell, Tony. "Portolan Charts from the Late Thirteenth Century to 1500," in *The History of Cartography,* volume one, *Cartography in Prehistory, Ancient, and Medieval Europe and the Mediterranean*, eds. J.B. Harley and David Woodward. Chicago: University of Chicago Press, 1987, pp.371-463.