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.

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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

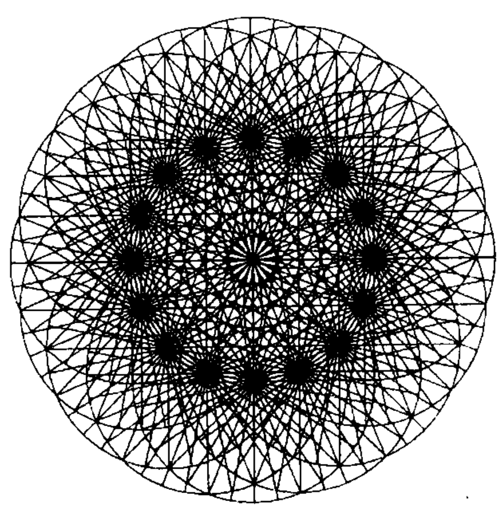

Fig. 1. Rosette generated using CAD software

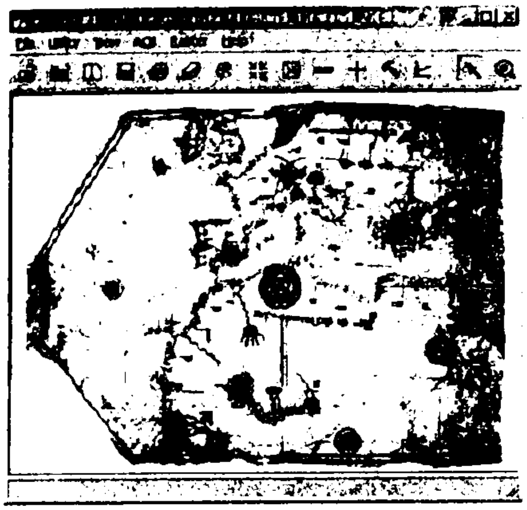

Fig. 2A. Original map loaded into Viewer 1

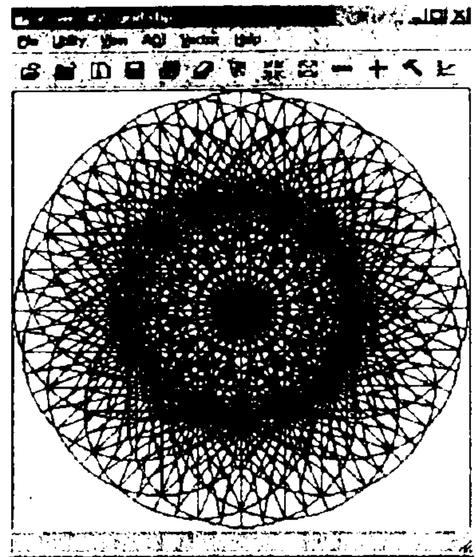

Fig. 2B. Rosette loaded into Viewer 2

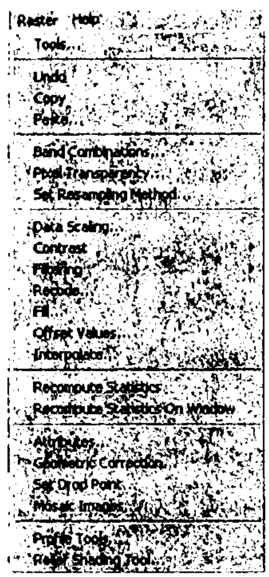

Fig. 2C. Options in the raster image viewer

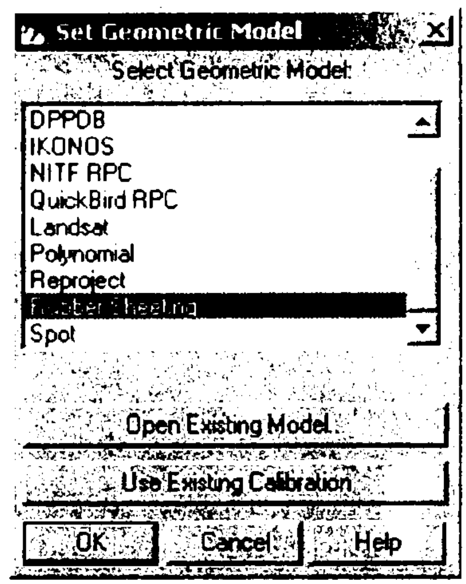

Fig. 2D. Geometric models dialog box

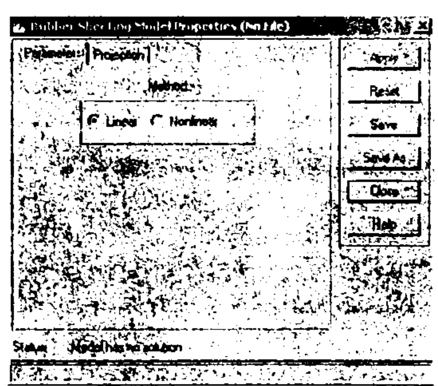

Fig. 2E. Rubber sheeting model parameters dialog box