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Methodology for the metric restoration of the historical cartography applied to Francisco Coello´s cartografic series of the Royal Site of Aranjuez

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Abstract

This study presents a process for restoring part of the 1860s cartographic series known as Hojas Kilométricas (Kilometric Sheets). Specifically, the study focuses on those sheets referring to the city centre and surrounding area of the Royal Site of Aranjuez, a town in the south of the Province of Madrid.

The aim of this study is to restore the actual size and measurements of scanned images of the Hojas Kilométricas. This would allow us, among other things, to reestablish both the format and scale of the original plans. To achieve this goal it is necessary to rectify and then georeference these images, i.e. assign them a geographic reference system.

This procedure is essential in the overlaying and comparison of the Hojas Kilométricas of the Royal Site with other historical cartography as well as other sources related to the same area from different time periods. Subsequent research would allow us, for example, to reconstruct the time-evolution of the urban area, to spot new construction and to pinpoint the locations of any altered or missing buildings or architectural features. In addition, this would allow us to develop and integrate databases for GIS models applicable to the management of our cultural heritage.

1 Introduction

In recent years, research on historical cartography has gone from being purely bibliographical and documentary to being more practical, with an increasing interest in metrics and accuracy aspects of those documents. Along these lines, we have been working in the Department of Cartographic Engineering, Geodesy and Photogrammetry-Graphic Expression of the Polytechnic University of Madrid (UPM), where this paper was created.

Our objective is the metric study of the *Hojas Kilométricas* (from this point represented as "*HK*"), plans created in the 1860s, concerning the urban area and surroundings of the Royal Site of Aranjuez, a town located in the south of the Province of Madrid. This Royal Site includes, apart from the summer Palace of the Kings of Spain, buildings, gardens and annexed walkways as well as orchards, agricultural buildings, and agricultural land.

Our purpose is to recover the real size and measurements of the original *HK* plans from their scanned images. This will allow us to restore their original format and scale. To achieve this goal, it is necessary to adjust these images and then georeference them, thereby assigning them a geographic reference system.

2 Background

In this study, we tend to contribute to answering the question posed by Ortega Vidal, J. (2000): How accurate and reliable, in their dimensional and formal aspect, are the fundamental plans of the past of the city of Madrid. In this case, we focus on the analysis of Aranjuez´s *HK*. The methodology consists of a historical study of each plan through graphical and geometric analysis. The results obtained from this study will be applicable in both types of analysis, though it will have a more direct practical application in the second. As a specific precedent for this study, there is the communication *"Las Hojas Kilométricas del Real Sitio de Aranjuez: un ejemplo de la cartografía española de finales del s. XIX"*, that we presented at the International Congress of Graphics Engineering, held in Perugia (Italy) from 6 to 8 June 2007. In this communication, we studied the "*Hojas Kilométricas"* from a historiographical point of view, placing them in their historical context [1]. Geometric correction methods will be used to rectify and georeference images from antique and historical maps and plans. These methods have been applied to images from different sources or sensors. A detailed review of the best methods for each type of image and its working process is available in Toutin 2004.

3 Materials

This study was conducted using the images of the *HK* plans of the Royal Site of Aranjuez scanned by the Spanish Geographic Institute (IGN) and cartography of the Province of Madrid at 1:5.000 scale, updated in 2004 in digital format (vector files and orthophotos), as sources of reference for the georeferencing process.

3.1 The "Hojas Kilométricas" of the Royal Site of Aranjuez

The *HK* constitute a set of 3000 plans, at 1:2.000 scale, which represent 1 km^2 areas of various municipal territories of the Province of Madrid. They are part of a great unfinished cadastral project that, driven by Francisco Coello, carried out in the 1860s by Topographic Cadastral Operations sections of the General Statistics Board of the Government of Spain. For this project, the entire Spanish territory was divided by a grid of parallels and meridians, equidistant at 1 Km, using the Astronomical Observatory of Madrid as the coordinate origin [2]. Of the 93 cadastral municipalities of the Province of Madrid, the Royal Site of Aranjuez is the largest one, with a total of 472 plans.

Fig. 1 Image of the "Hojas Kilométricas" 31-, 32-L. Original scale 1/2.000.

All of these documents are part of the collections that are preserved in the Technical Archive, assigned to the General Secretariat of the Spanish Geographic Institute (IGN). In this archive is stored a series of more than 6.000 topographical plans of cadastral nature. In addition to the *HK,* there are supporting documents and preliminary documentation: planimetries, drafts, sketches, tracings, notebooks of observations and calculation books, etc., in short, the sources of the work [3].

In this study, we will use nine of the total *HK* of the Royal Site of Aranjuez: Numbers 30-, 31-, and 32-K; 30-, 31-, and 32-L and 30-, 31-, 32-M, which includes the city centre and surroundings. Images of two of them – numbers 31- and 32-L-, which belong to the historic centre are shown (Figure 1).

3.2 Orthophoto and vectorial cartography

The orthophoto we will use, according to the new nomenclature adopted by the Province of Madrid, in which each sheet in vector format ("dgn" format) corresponds to two orthophotos ("ecw" format), is as follows: Vector 05-59-24.dgn and Orthophoto: 05-59-24-a.ecw.

The reference system in both cases is ED-50, UTM projection, zone 30. Both images are shown below in Figure 2.

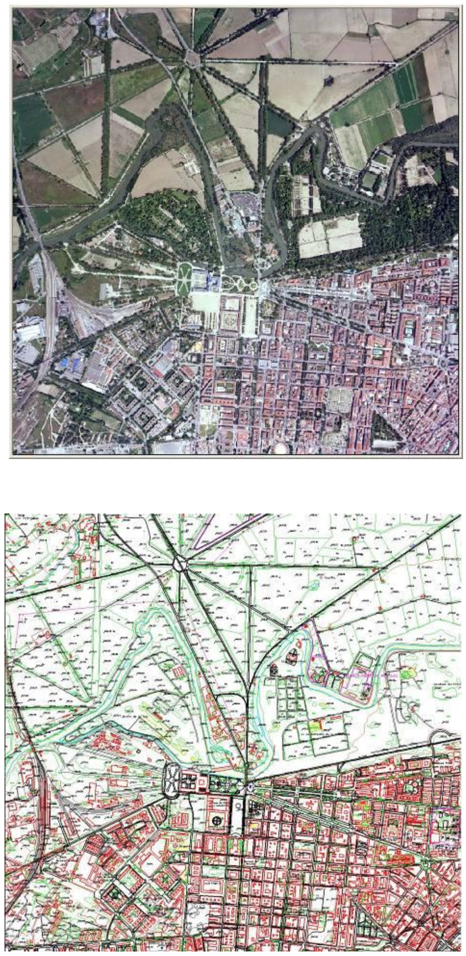

Fig. 2 Orthophoto: 05-59-24-a.ecw; Vector 05-59-24.dgn; of Aranjuez. Scale 1/5.000.

4 Methodology

Unprocessed digital images are affected by a series of distortions that result in geometric errors, caused by several factors, with the result that objects do not appear represented in their real shape and/or position. Therefore, unprocessed images cannot be used as cartographic documents for analyses that require some level of metric or geometric accuracy [4].

The origin of distortions and the importance of each source of error to the total error mainly depend on the image capture system used. In our case, images were obtained by scanning the original document. Geometric Correction solves these problems and involves a geometric transformation (adjusted to the chosen coordinate system), modification of the pixel size and assignment (if necessary) of new digital levels, creating a new image from the original.

In practice, procedures for geometric correction of images can be classified into two large groups: those that incorporate a digital terrain model and those that do not. These methods of correcting displacement errors caused by terrain are called orthorectification and rectification methods, respectively [5]. All of these methods are based on adapting the image to a set of points of support (PS), of known coordinates, using an adjustment by the method of least squares. These points can be defined as identifiable points in the image, whose coordinates are also known in the cartographic projection system. One form of this rectification is Georeferencing, which refers to any geometric transformation applied to an image in order to provide it with a cartographic reference system [6]. The steps for the treatment and processing used in the geometric correction method are as follows [7].

Image acquisition.

Acquisition of points of support with both image and real X, Y, (Z) coordinates.

Calculation of parameters of the mathematical functions used in the geometric correction model, for one or more images.

Image rectification.

4.1 Rectification

In our study, we will use the rectification method. In this method, the coordinates of the points of support identified in the image are used to estimate adjustment functions between the two reference spaces. The two basic operations (Jensen, 1996) in the method applied in correcting the original image are:

Spatial interpolation: Establishing the geometric relation between the position of the pixel in the image (row, column) and the corresponding point on the map (X, Y) in order to later apply it to all pixels in the image.

Intensity interpolation: Determining the brightness value or Digital Level (DL) of the corrected pixels.

In this case, we have taken a total of 36 points of support for each *HK* (Figure 3). Points are regularly and homogeneously distributed on the images, covering most of each sheet, spaced every 100 or 200 m in both directions. They are located on the junctions which represent, as is written at the bottom of each sheet "*las cuadrículas de líneas finas que representan áreas y las líneas gruesas hectáreas"* (the grids of fine lines represent ares [100 m^2], and the thick lines represent hectares).

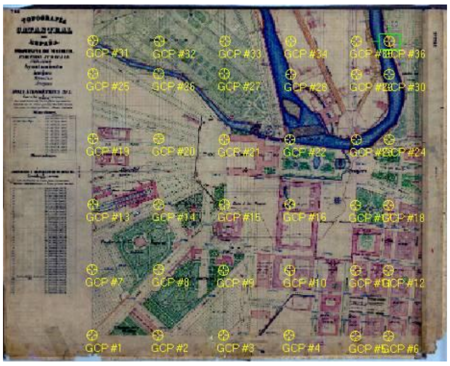

Fig. 3 Example of the points of support distribution on the HK 31L image.

The results of this stage of the process are as follows:

The values of the coefficients used in the geometric model in each image.

The residuals in the X and Y directions for each PS and its (RMS);

The cartographic coordinates computed for each point.

The quality of the geometric correction can be assessed by comparing, for each point of support, the coordinates estimated in the transformation with their real equivalents. The RMSE (Root Mean Square Error) is the most widely used indicator. The PS RMS error is calculated using a distance equation. The error is defined as the difference between the estimated output coordinate and the real output coordinate for the same point, when the point is modified by the geometric transformation. The resulting *Total* mean error, calculated from the residual values of all points in each *HK*, is below 2 pixels. This was the predetermined tolerance based on the scale of the plans and the precision with which we attempted to obtain results. Table 1 shows the total errors for each of the nine *HK* [8].

Hoja Kilométrica	Total error (pixels)
30-K	1.0613
31-K	1.0227
32-K	0.9727
30-L	1.1506
31-L	0.9951
32-L	1.0447
30-M	1.0545
31-M	1.0312
32-M	0.9955

Tab. 1 Total errors of the nine HK.

Fig. 4 Corrected output image.* HK *31-L.

Figure 4 shows the image obtained as a result of the entire geometric correction process. In this image, a Cartesian axis system is overlayed in yellow. Its origin of coordinates is placed at the lower left corner of the area corresponding to the *"Plano"* (graphical information of the sheet).

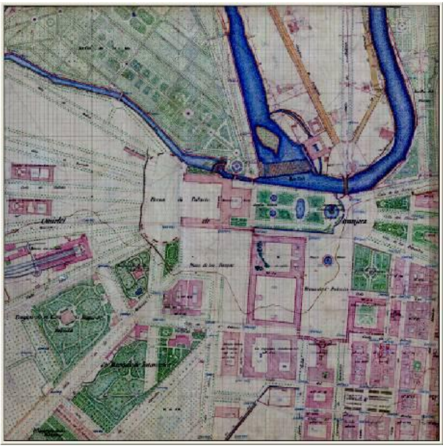

Fig. 5 Corrected output image.* HK *31-L.

Fig. 6 Mosaic diagram of the 9 HK

4.2 Cropping of images

The images obtained thus far contain an area larger than the area corresponding to the actual topographic plan. Therefore, it is necessary to reduce the file size by making a "crop" of the images and leaving only the area of interest. Using this process, we proceed to cut the area corresponding to the graphic information, in the topographic plan of the same, and separate it from the rest (Figure 5). Once they have been cut, the 9 *HK* have exactly the same size and the surface of each one represents 1 km^2 in real units. Subsequently, a mosaic will be created from the plans of the 9 *HK*:

4.3 Mosaic

The final plan will consist of several individual sheets covering the area of study. In this case, it is necessary to adjust the images to create a larger single plan. This process is known as "Mosaic" formation. Therefore, the objective of this process is to obtain a single image, resulting from joining the nine *HK*, as shown in the diagram of Figure 6. Before obtaining the mosaic, it is necessary to provide a translation, or change of coordinate origin for each one of the 9 files (so far, they have the same coordinates). Thus, when they are placed in their correct position within the large single plan, without spaces between them, they form a continuous map (Figure 7).

Fig. 7 Mosaic with the 9* HK *.

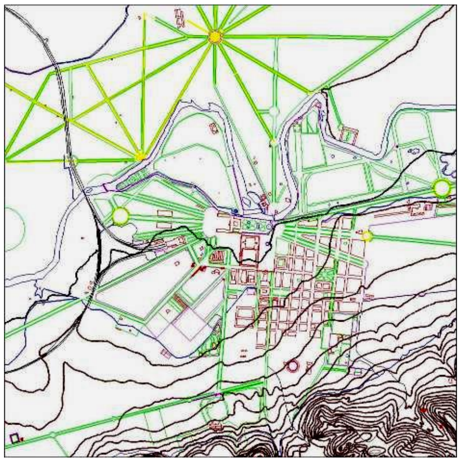

Fig. 8 Corresponding vector plan.

4.4 Georeferencing

In order to compare the mosaic obtained with a recent orthophoto from the CAM (*Comunidad Autónoma de Madrid*) and carry out further studies, it needs to be georeferenced, so that both documents have the same projection and coordinate system.

Therefore, it will be necessary to align the mosaic´s coordinates, which are in principle local, with those of the orthophoto. To do this, a translation of coordinates will first be made, taking as a point of origin the upper right corner of the "Casa de Oficios y Caballeros" (House of Trades and Knights) of Aranjuez, and as a point of destination, the coordinates of the same point of the building obtained from the CAM vector plan.
After obtaining the mosaic, the process of georeferencing with UTM coordinates is completed through the allocation of the corresponding cartographic projection system by applying the parameters from Table 2.

Projection type	Ellipsoid	Datum	Zone	Hemisphere
UTM	International 1.909	ED-50	30	North

Tab. 2 Data of the Projection System.

Once we have referred the *HK* with the same reference system as the CAM orthophotos, planimetry and altimetry details are digitized in order to obtain a vector plan from the raster (Figure 8). From this moment, it is possible to overlay and make subsequent comparisons between the four types of maps available: the mosaic composed of HK, the orthophoto, and the vector plans of both.

In the following images, (Figures 8 and 9), two original images are shown overlaid with the vector representations of their counterpart. We do this because, while it is obviously possible to overlay the vector files onto the images to which they belong, it is now also possible to overlay the CAM vector cartography of the same area onto the raster of the georeferenced mosaic and *vice versa.*

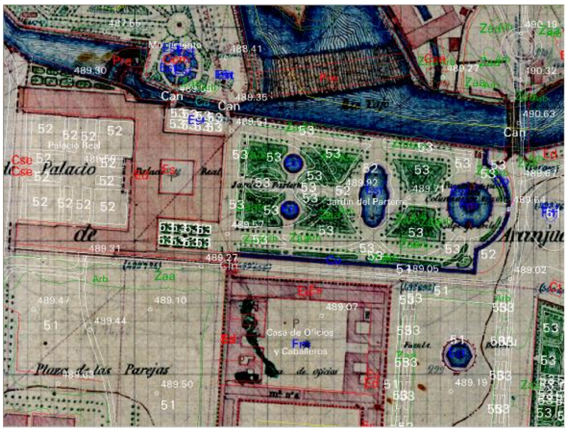

Fig. 9 CAM vector cartography overlaid on the HK Mosaic. Enlargement of the Royal Palace and Parterre garden area of Aranjuez.

Fig. 10 Vector of the mosaic overlaid on the orthophoto. Enlargement of the Royal Palace area.

Finally, an image is shown (Figure 11), in which we can simultaneously see two raster images of the same area: the orthophoto and the *HK* mosaic.

Fig. 11 Image composition: The orthophoto at the top and the HK mosaic at the bottom.

5 Conclusion

Once the images of the *Hojas Kilométricas* plans have been rectified and georeferenced, we can conclude that:

The process of metric restoration applied to the *HK* of the Aranjuez area has been shown as an adequate methodology for the recovery of antique and historical maps and plans. This produces documents with metric properties that allow us to obtain such measurements as longitude, area, perimeter and angles, as well as to specify directions. Moreover, it is possible to vectorize, transform the information from raster to vectorial and *vice versa*, in order to overlay raster images with vector data.

On the other hand, rectification allows the formation of image mosaics by joining several adjacent sheets of larger areas, which makes the analysis of wider environments easier. It also allows us to compare cartographic images that were originally created in different scales, together with the possibility of developing and integrating GIS model databases, which are applicable to the management of cultural heritage.

Applied georeferencing allows the integration of the document obtained by information from different sensors or other current sources, such as orthophotos, satellite images, DTM or vector plans of the same area at different times. The purpose of this is to analyze the evolution and changes of the territory, and to detect new constructions, building layouts, disappearance of architectural elements, and location of goods, among other elements of interest.

Due to the antiquity of these types of documents, it is extremely difficult to establish equivalent points between the source document and any that are more current. So, it is essential for these documents to possess a cartographical grid. This grid allows the selection of points of support on a uniform grid, which are necessary to correct the distortions due to the original medium (paper) and the digitization technique used. This is independent of the changes undergone by routes, urban areas and buildings.

The quality of the product obtained is determined by the spatial resolution of the digital file, with resolutions over 200 dpi recommended in order to avoid loss of detail that would make adequate rectification of the original documents impossible.

To complement this study, we intend to apply our work to the cartographical quality control of the original maps and other historical cartography. We will analyze the precision and positional accuracy of the same, particularly in terms of planimetry. In this phase, which has already begun, we will employ the different applicable standards for the control of cartographic products established by international organizations.

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