# Methods for document image de-warping

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The problem for design of methods and algorithms that can automatically extract data from digitized astrographic plates Laskov and Tsvetkov (2013) incorporates a number of techniques that are usually met in the field of document image processing. One of the problems that arise is the task for automatic software rectification of scanned document pages that suffer from curvature distortion due to the physical folding of the paper that has been captured by a digital camera or a scanner.

In this paper we present some of the state of the art techniques for document image de-warping. Our goal is to examine the existing methods, and to investigate their possible application in the image processing and pattern recognition techniques used in astrographic plates automatic data extraction.

*Keywords:* Carte du Ciel; Pattern recognition; Document image processing; Image de-warping

## 1. Introduction

Astrograhic plates, and their paper copies called *astrographic maps*, provide data for many research works in the field of astronomy. Even though modern instruments exist that can produce much better quality and more detailed data, many of the plates are even a century old which makes them a valuable data source. However, investigating these plates usually involves time consuming and expensive manual searching and analysis.

The later motivates the creation of digital databases of digitized (scanned) images of astrographic plates and digitized astrographic maps. These databases vastly speed up the process of searching for a particular plate image and, of course, tremendously increase the accessibility of the plates. Such database is the Wide-Field Plate Database (WFPDB) that is available on Internet at the address `http://www.skyarchive.org/`.

One of the catalogues that are currently included in the WFPDB project is composed by Carte du Ciel plates that were originally collected at the Royal Observatory of Belgium. The database contains 682 scanned astrographic maps that are copies of the Carte du Ciel plates, taken by the Gautier 0.33-m equatorial telescope in the time interval 1908-1939. Detailed information about the database and the Carte du Ciel plates images contained in it can be found in Tsvetkova et al. (2007).

A special interest of our research are exactly the astrographic maps of the Carte du Ciel project. These maps are paper copies of the original astrographic plates that were produced using the technique of photogravuere on copper plates. The paper copies are twice the size of the original plates, and are scanned with resolution of 600 ppi producing relatively big bitmaps of approximately $8750 \times 8926$ pixels. A fragment of such image is given on Figure 1, selected from the top part of an astrographic map.

One of the reasons why these images are an object of special attention, is the method that was used when the plates were exposed. Each plate contains three expositions, each in duration of approximately 20 minutes, thus producing a triple image

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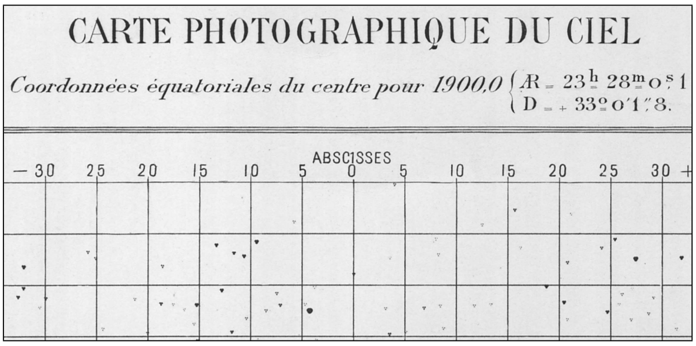



Figure 1: Fragment of the top part of an anstrographic map

for each star on the plate, called an *asterism* (see Figure 2). These asterisms were originally used to calculate the exact stellar coordinates, and also to distinguish stellar images from other objects, such as asteroids, for example. On the other hand, the asterism itself can contain a valuable data about the star. In a case in which there is a significant difference between the standard deviations $\sigma$ of the Gaussian distributions of the three stellar images, we can assume that the observed star is a variable star.

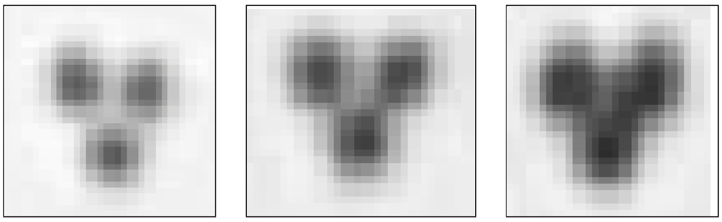


Figure 2: Example of three different asterisms. Each star is presented by three images that form an equilateral triangle

The above is only an example of a problem that naturally posses the question for computer processing of the described images, and development of methods and algorithms that are able to extract data automatically from them. Development of such approaches is a subject of the fields of image processing, pattern recognition, and in some more particular cases, document image processing, as it is shown in Laskov and Tsvetkov (2013).

The computer processing of images of astrographic maps include different stages, in which the quality of the image is enhanced. These stages may incorporate algorithms for noise reduction, and various artefacts removal, for example the automatic detection of the perpendicular grid printed on the original astrographic plates. One of the specific distortions that has to be examined is the curvature distortion, that is present in the images.

The curvature distortion is due to the plate acquisition process itself, and physical characteristics of the paper on which the maps are printed. The process of removal of this type of image distortion is a known problem in the field of document image processing, and it is usually referred to as *document image de-warping*.

Even though document image de-warping is a problem that has been extensively investigated in the last few decades, there is no standard common solution. There are a number of different approaches published, most of them attempting to straighten images of thick bound volumes. The goal of this paper is to examine some of the state of the art techniques for document image de-warping, and to analyze their possible application in the case of the digitized astrographic maps.

This paper is structured as follows. The next section describes the geometric distortions in astrographic maps. Section 3 presents the problem for document image de-warping in its original domain – the OCR systems. Sections 4 and 5 give survey of the existing methods, and also attempt to classify different approaches that exist in the literature. The final section discusses the possible application of the presented methods in the case of digitized astrographic maps.

## 2. Astrographic maps geometric distortions

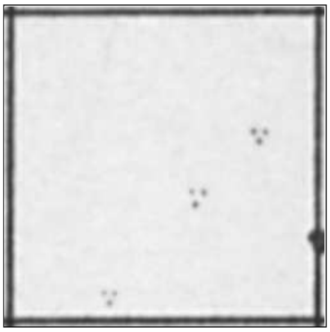
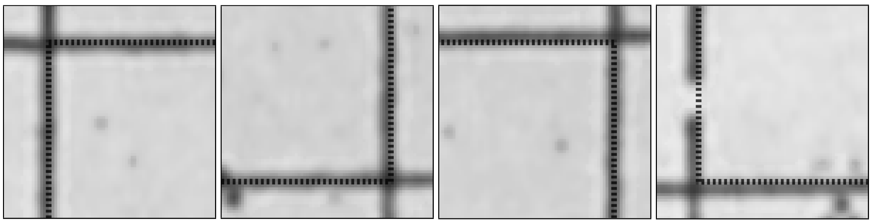


Figure 3: An arbitrary grid square from an astrographic map, together with grid axes

The structure of the astrographic maps itself can be particularly in use for detection of geometric distortions in the images. The reason is the square grid that is printed on the original plate before its development (see Figure 1). The name of this coordinate system is *resean* and its original purpose is the measurement of the stars positions, as described in Tsvetkova et al. (2007). It is composed by 27 horizontal and 27 vertical straight lines with step of 5 arcmin that divide the plate into 169 equal squares. Each of these grid squares (see Figure 3) are approximately $250 \times 250$ pixels in the image bitmap, measured together with the grid itself, which is approximately 10 pixels in width. The vertical axes are numbered starting from 0 in the center of the plate up to 60 with step 5 at both left and right direction. The numbering of the horizontal axes is the same, but in vertical direction.

Since the axes of the grid are supposed to be absolutely straight, they can be used to detect if there is a geometric distortion in the image, of course in a scale that could affect them.

The first scale in which geometric distortion can be observed is the scale of the individual grid square. Suppose that we try to fit a perfectly drawn "artificial" square on top of a grid square. If the top-left and bottom-right corners of the two squares coincide we can expect that both geometric figures are going to be identical. Because of the geometric distortions in the image, the grid square does not fit perfectly with the artificial one, which is visible at its bottom-left and top-right corners (see Figure 4). Since the images were perfectly adjusted during the scanning process, the reason for this shift in the geometric shapes can be found in the paper curl on the map surface that

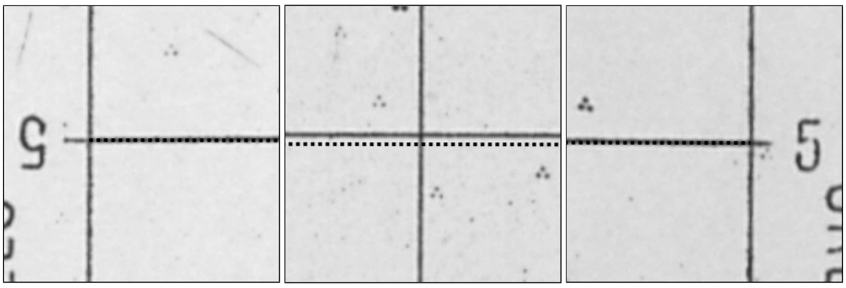


(a) (b) (c) (d)

Figure 4: The four corners of a grid square: (a) top-left corner; (b) bottom-right corner; (c) top-right corner; and (d) bottom-left corner. The dotted line represents an artificially drawn perfect square

is caused by the physical properties of the astrographic maps themselves.

The second scale in which the grid axes can be used to detect geometric distortion in the image is the scale of the entire image itself. If we draw a straight line that connects the left and the right endpoints of a horizontal axis, then the two lines will coincide if the grid axis is perfectly straight. However, the experiment on Figure 5 shows that in the middle of the image the straight line does not coincide the grid axis. In this particular example the straight dotted line connects the two end points of the horizontal axis that is numbered 5. The fragment of the image shown in the Figure 5 (b) is in the middle of the plate, exactly at the vertical axis numbered 0. Even with a naked eye it is visible that there is a significant diversion (in about 10 pixels) that shows that the axis is not straight, but actually it is slightly bended in the shape of an arc.



(a) (b) (c)

Figure 5: The dotted straight line connecting (a) the left endpoint, and (c) the right endpoint of a horizontal axis, does not coincide with it in the middle of the image (b)

This geometric distortion is observed in the horizontal direction, but it is not observed in the vertical one. The reason for it can be found in the physical processes that were used to produce the astrographic maps.

The problem of detection and correction of such image curl is a know problem in the field of document image processing, and it is usually referred to as *document image de-warping* (see for example Shafait and Breuel (2007)).

## 3. De-warping in the context of OCR systems

The detection and correction of geometric distortions in images that are caused by the physical curl of the original paper source, and also because of the process of image acquisition, is a problem that was seriously considered in the last few decades in development of non-standard optical character recognition (OCR) systems. Commonly two separate problems are investigated: document image de-warping, and projection distortion removal (see Ulges et al. (2005), Kakumanu et al. (2006)).

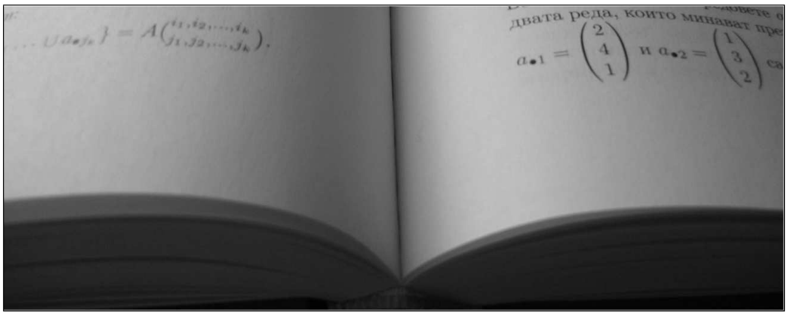



Figure 6: A thick bound volume image taken with a digital camera. Both page curl and perspective distortion are visible

In many of the investigated cases, a thick bound volume is digitized using a digital camera instead of a flat-bed scanner. The image curl is a result of the physical bound of the pages because of the book structure, and perspective distortion is introduced by the angle between the optical axis and page surface (see Figure 6 and Figure 7). The reasons why a digital camera may be used instead of a flat-bed scanner can be various. For example, the camera of a mobile device may be used to digitize texts, and to send the data to an OCR program on the device itself (Zhang and Tan (2007)). With the development of modern mobile devices, such a scenario is more and more topical.

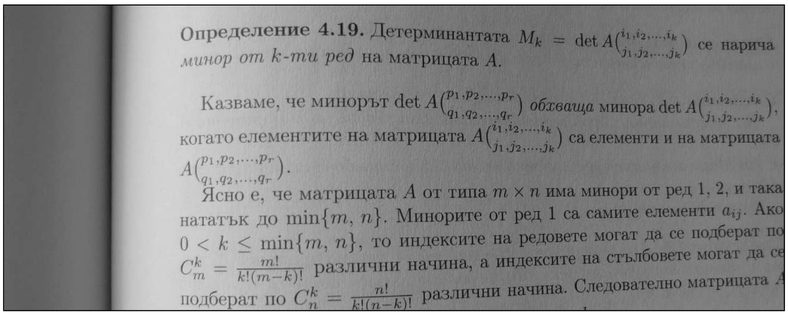



Figure 7: A thick bound volume image taken from above. Textual lines are bended due to the page curl

Another scenario may be the digitalization of valuable historical manuscripts, which cannot be transported from their depository (Laskov (2011)). A standard flat-bed scanner cannot be used on such documents because they can be damaged by the physical pressure and heat of the device. Often, the specialize equipment, such as special non-contact scanners, designed to work with fragile books, also cannot be used, simply because they cannot be transported to the place where the books are preserved. In such cases, the standard digital camera is the only solution.

But even if a flat-bed scanner can be used, still the digital image may contain page curl distortion close to the spine of thick books. In this case the problem for document image de-warping still exists, and is addressed to by number of works (Zhang et al. (2004), Ezaki et al. (2005), Zandifar (2007)).

Since the above mentioned scenarios can be observed in more ore less special cases, the standard OCR software does not solve the de-warping problem. Usually standard commercial software requires images of good quality with straight textual lines. However, in many non-standard applications, de-warping is an important and crucial step, and it is an objective of extensive research in the field of document image processing. The existing methods in the literature can be classified according to image acquisition device, according to the usage of special equipment, and according to the algorithm approach.

According to image acquisition device the methods are divided into algorithms that work on: (i) images acquired using flat-bed scanners or other specialized equipment; (ii) images acquired using standard digital cameras. As mentioned above, in both cases the page curl is observed. The main difference is in the perspective distortion, which in the second case is naturally more expressed.

According to the usage of special equipment the methods are divided into: (i) methods that require additional specialized equipment; and (ii) methods that relay on the image only. The second group is much more interesting, because of the cost of the usage of additional equipment. Also, in many cases the usage of special hardware devices may not be possible.

According to the algorithm approach the methods can be divided into: (i) 3D page shape reconstruction; and (ii) 2D image processing techniques. This classification is the most interesting for us, also because of the goal of incorporation of a de-warping algorithm in the case of astrographic maps images. In the following two sections we will discuss in more details these two groups of methods.

# 4. 3D page shape reconstruction techniques

In general, the goal of 3D page shape reconstruction techniques is to develop a reconstruction of the curled page surface in three dimensions. The result of the reconstruction is a 3D page surface model that is used to formulate a procedure that reduces or eliminates the page curl and perspective distortions in the input image. Most of these methods either relay on some a priori knowledge about the optics of the camera or device used to digitize the document, or attempt to extract such information from features that are present in the input image.

The first type of features used to recover page surface shape on which we will focus, is the shading in the input images. Traditionally, methods that attempt to recover an object's shape based on shadings in the observed scene or image, are called *shape-from-shading techniques*. Methods that use shape-from-shading to build a 3D model of the page surface are presented in Zhang et al. (2004) and Zhang and Tan (2007).

In Zhang et al. (2004) de-shading and de-warping schemes are proposed that are based on an optical model of a bound book. The schemes do not rely on textual lines, but authors use precision and recall metrics of the result of an OCR software to validate their result. Two problems are addressed: de-shading of the document image, and restoration of the page shape. For that purpose, authors propose two models. A geometric model that represents the page surface shape as depth $z$:

$$z(y_j) = \sum_{y_k=y_{N-1}}^{y_j} \tan\left(\phi(y_k) + \psi\right), \quad \text{if } \phi(y_k) > \psi, \tag{1}$$

where depth $z(y_j)$ is presented as the distance between scanning plane and page surface, $\phi(y_k)$ is the slant angle of the book surface at $y_j$, and $\psi$ is the angle between light source direction and normal of the scanning plane.

The second model proposed is the optical model that is used to estimate the page surface:

$$z(y_j) = \left[\frac{(P_w^{max} - \beta)\cos\phi(y_j)}{(P_w(y_j) - \beta)cos\phi} - 1\right] d_2, \tag{2}$$

where $P_w^{max}$ is global maximum pixel value, $P_w(y_j)$ are pixel values corresponding to the background, and $\beta$ and $d_2$ are parameters from calibrated image. Then, de-warping is performed based on the estimation of the page surface given in by the optical model (2).

The approach proposed in Zhang and Tan (2007) is based on 3D shape reconstruction and modelling composed by two main stages: 3D page surface restoration using shape-from-shading, and page surface de-warping using a physically based deformable model. For the first stage, the authors extract the shading information from the input image using adaptive thresholding technique and interpolation. The resulting shading image is used to apply the shape-from-shading algorithm that is based on fast marching numerical partial differential equation (PDE) solution. The resulting 3D surface of the page is presented by a set of 3D points connected in triangular mesh. An approach to flatten the 3D mesh is used that is borrowed from computer graphics method for simulations of dynamic deformations of physical materials by reversing the deformations step.

The second type of 3D page shape recognition techniques is based on some assumption for the geometric shape of the page curvature. Some of the methods assume the geometric shape a priori. For example Wu et al. (2007) and Meng et al. (2012) suppose that the page surface has cylindrical shape. Such assumption can be considered reasonable in the case of thick bound volumes, as the example on Figure 6.

Another approach is to conduct some kind of experiment that gives an approximation of the geometric shape of the page, for example the method proposed in Sutapirat et al. (2009). In any of these cases the de-warping process can be described (keeping the notation of Sutapirat et al. (2009)) by the relation:

$$f(x', y') = T\left(f(x,y)\right), \tag{3}$$

where $f(x', y')$ is the Cartesian coordinate system of the de-warped surface, $f(x,y)$ is the coordinate system of the curved surface, and $T(\cdot)$ is the de-warping function that is a coordinate transform that is given by the concrete method.

The coordinate transform (3) in Wu et al. (2007) is given by a relation between a curled net that models the surface of the curled page, which is stretched to a straight net. The method searches for a region on the curled page that must correspond to a square in the straight image. This region is given by the detection of two document lines, and left and right boundaries of the textual area.

The method proposed by Meng et al. (2012) is based on general cylindrical surface, and an isometric mesh construction. The mesh is fitted on the input image based on at least two curved horizontal text lines extraction and their B-splines fitting. The function that rectifies the image in this case is based on the pointwise bilinear resampling that has been proposed by Brown and Tsoi (2006).

The third type of 3D techniques on which we will focus, is based entirely on the segmentation of the input images. The methods that fall into this group use the extracted textual lines to build the model of the curved page surface in 3D. Usually, the main assumption is that the textual lines are straight in the original document.

An example of such method is the one given in Ulges et al. (2005). Here authors propose text line segmentation based on a modification of the RAST (Recognition by Adaptive Subdivision of Transformation Space) algorithm, which is a method for geometrical model fitting. The algorithm first segments each individual character in the input image as a linked component and calculates its bounding box. Given a set of bounding boxes, an optimal base line is discovered using the modified RAST method, which models the textual line. Then, the proposed 3D model is:

$$p' = (\lambda(u-u_0), \lambda(v-v_0), d)^T \in \mathbb{R}^3, \tag{4}$$

where $p'$ is the 3D point that is projection of the image point $p = (u, v)$, $(u_0, v_0)$ is the principal point of the camera (intersection of the optical axis and the image plane), $\lambda$ is a value to compensate for the perspective projection, and $d$ is the depth value.

# 5. 2D image processing techniques

The category of methods that are based on 2D image processing techniques do not rely on any kind of a priory knowledge, for example about camera or scanner parameters, or geometrical shape of the page curl. They are based only on features extracted from the image content. Also, they do not attempt to reconstruct the physical structure of the surface of the page, but rather they try to recover and discover the information of interest directly in the 2D image.

The most commonly used feature extracted from the image content is the estimation of textual lines. Again, the basic assumption is that in the original document the lines are straight. Then it may be assumed that the curvature of the lines gives the curvature of the entire image.

A common approach is to use bottom-up method firstly discovering the connected components like symbols and words (see Zandifar (2007) and Gatos et al. (2007)). Another bottom-up approach is Kakumanu et al. (2006) that is based on RANSAC (random sample consensus) method that estimates the lines from the characters bounding boxes, previously discovered as connected components of pixels. Then each character belonging to a given line is transformed so that a straight line is formed in the output image.

As a contrast, a top-down approach for image segmentation to discover the textual lines is adopted by Schneider et al. (2007). The authors use horizontal projective profiles of the image and Sobel filter to discover the baselines of the textual lines.

Many of the 2D image processing techniques use polynomials and splines to model image features, and to de-warp the image based on this model. The most common feature modelled are the textual lines discovered by a previous stage of the method, like in Schneider et al. (2007), Zandifar (2007) and Stamatopoulos et al. (2008).

Sometimes, instead of modelling the lines, the gaps between them are preferred (see Ezaki et al. (2005)). Compared with the textual lines, the gaps between them are much more compact and dense as pixel values, and are not broken, as usually textual lines are.

Not always all the discovered lines are used to build the polynomial representation. For some of the methods it is enough to represent only the top and the bottom lines (Zandifar (2007), Stamatopoulos et al. (2008)). These approaches suppose that the shape of the entire page can be modelled by the curled top and bottom lines, while the text boundaries on the left and right are assumed to be straight.

After building of the polynomial model for the textual lines, the de-warping process itself can be based on various approaches. For example, in Schneider et al. (2007) the lines representation is used to construct a vector field that corresponds to a mesh which approximates the nonlinear geometric distortion. Each mesh quadrangular is then projected into a rectangle in the resulting de-warped image.

In the case in which the curl of the image is represented by top and bottom textual lines polynomials, Zandifar (2007) propose a procedure based on the blending of the two lines function, while Stamatopoulos et al. (2008) preforms image correction in two stages: coarse and fine de-warping. The coarse de-warping is performed by a transformation model that maps the curved image into a rectangular one. For the second stage, the image is segmented again and individual transformation is applied to each discovered word as a connected component.

Ezaki et al. (2005) uses the splines that model the gaps between lines to formulate a model fitting method. An optimal fitting model as minimization of a criterion function $J$ that evaluates the fitting of the splines is proposed:

$$J = \sum_{i=1}^{H} \{ f(\theta_i | i) + \omega \lambda (\theta_i, \theta_{i+1}) \}, \tag{5}$$

where $H$ is the number of splines that represent gaps between lines, $f(\theta_i|i)$ evaluates difference between spline model and actual warp, $\theta_i = (\alpha_i, \beta_i, \gamma_i)$ represents the $i$-th spline, $\lambda(\cdot,\cdot)$ is a regularization function, and $\omega$ is a positive constant.

Polynomials and splines are not the only approach to model geometric features in de-warping methods, there are also geometric models that usually are applied in much more different applications of image processing. For example, in Kakumanu et al. (2006) horizontal and vertical *vanishing points* are used, that are usually adopted in computer vision applications, such as motion detection and navigation in robotics, etc. In this work, vanishing points are used to remove the perspective distortion from document images taken by digital camera. The method relays on the fact that under perspective projection all originally parallel lines are intersecting in a single point, that is exactly the vanishing point that corresponds to them.

Another approach is the *image mosaicking* that is used in Tong et al. (2011). This method is more often applied in methods connected with wide format photography, for example in generation of panorama images. In Tong et al. (2011) the input of the algorithm is composed by two images of the same document page. The algorithm constructs a single image out of them that contains reduced curvature distortion.

# 6. Discussion

Even though document image de-warping is a known problem in the field of document image processing, there is no standard solution applicable in most of the cases. The recent rapid development of the hardware devices actually does not ease the tasks of the software, but rather poses new challenges in front of the applications, and document image de-warping is a good example for this tendency. In contrast to device evolution, most of the authors prefer not to use additional hardware devices in their solutions, since it is an expensive approach, but rather prefer the usage of standard digital cameras or flat-bed scanners.

The approach to develop a 3D model that reconstructs the surface of the curled page, and to define the de-warping procedure based on it, is a natural solution because the origin of the problem itself is three-dimensional. These type of methods tend accurately to present the structure of the page curl, of course depending on the initial information they are given. Some of them actually rely on 2D features present in the image, like shape-from-shading techniques, or techniques based on textual lines extraction. On the other hand, many methods are based on camera parameters – an information that not always is available. The assumption for the shape of the page curl can be relative in the particular application, but unfortunately it cannot produce standard solution. For example, the cylindrical model may apply in the case of the bound volumes, but it is not relevant in our case of astrographic maps processing. Also, despite of the 3D model used, these type of methods are always heavy and expensive, and after all the goal is geometrical distortion reduction in the 2D image itself, not the restoration of the entire complex 3D scene. Also, the astrographic maps were digitized using a special scanner equipment, they do not contain perspective distortion and do not represent a complex 3D scene, hence we can conclude that the rectification of these images is more or less a 2D image processing problem.

2D image processing techniques are more practical since they work in the same domain where the final solution is needed – the bitmap of the image. However, many of the existing methods rely on textual lines segmentation, and even words and symbols segmentation directly in the distorted images, which can be a heavy task. Something more, if images are correctly segmented, then the de-warping can be a redundant stage. Also, many of the methods duplicate the segmentation step: one before, and one after de-warping procedure. In some of them, only de-warping of the textual lines is performed which actually does not fix the geometrical distortion of the individual graphical elements, such as characters and symbols, that can influence the recognition stage. From the point of view of our problem, we need a method that will rectify the entire image, not just reorder its graphical elements to form straight image features.

On the other hand, the application of 2D image processing techniques are not going to suffer these problems in the case of the astrographic maps processing. The reason is the structure of the maps that was described in Section 2. The square grid in the images is easily detectable, and it is not the goal of the de-warping, even though it can be the feature used to perform the correction, since the idea is to reduce the geometric distortion in the stellar images and to correct their positions in the astrographic map.

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