METHODS FOR DOCUMENT IMAGE DE-WARPING

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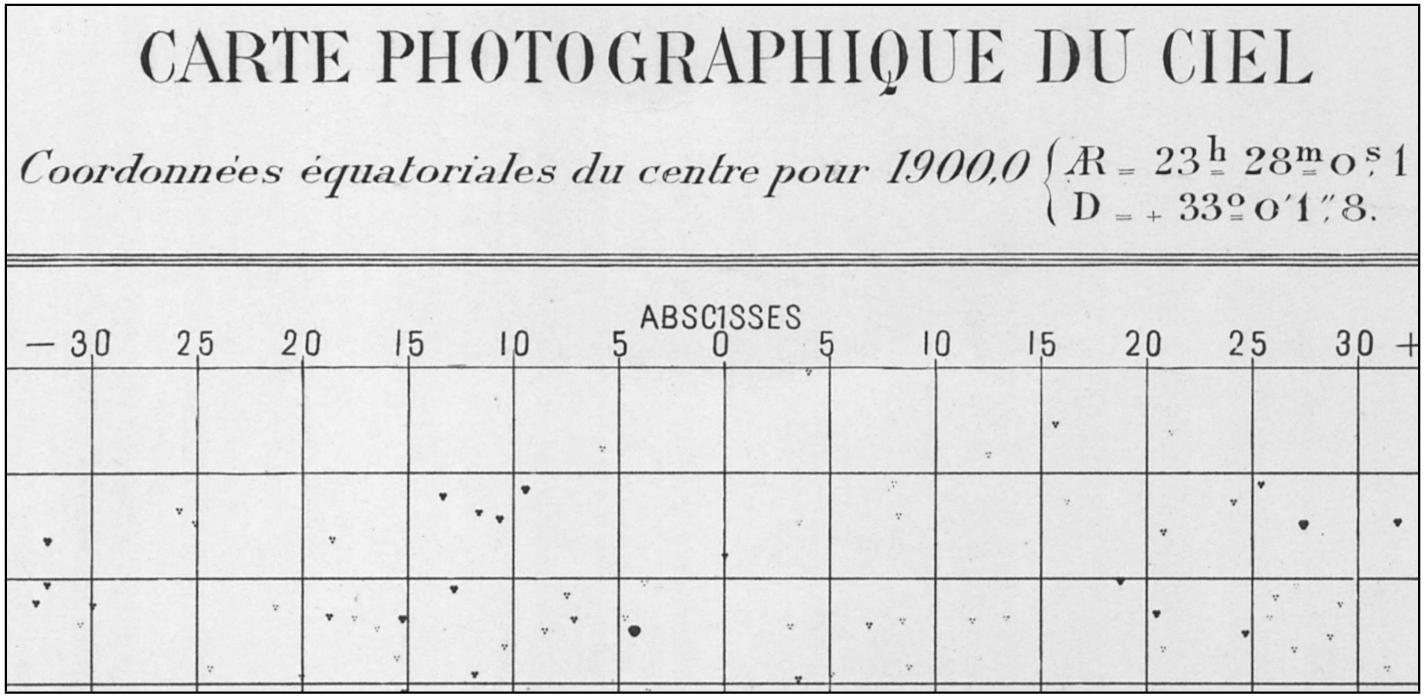
1. The problem
2. Document image de-warping
3. 3D page shape reconstruction
4. 2D image processing techniques
5. Discussion

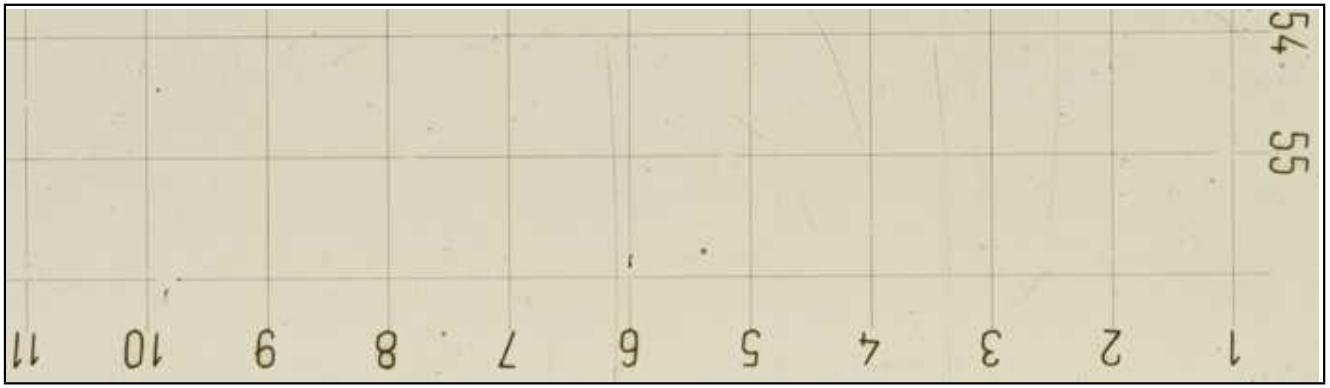
Carte du Ciel



Carte du Ciel project:

- part of 19th century extensive astronomical project;
- *the goal* was to map the entire visible sky;
- *the result* is preserved in the form of *asrtographic plates*.

Astrographic plates



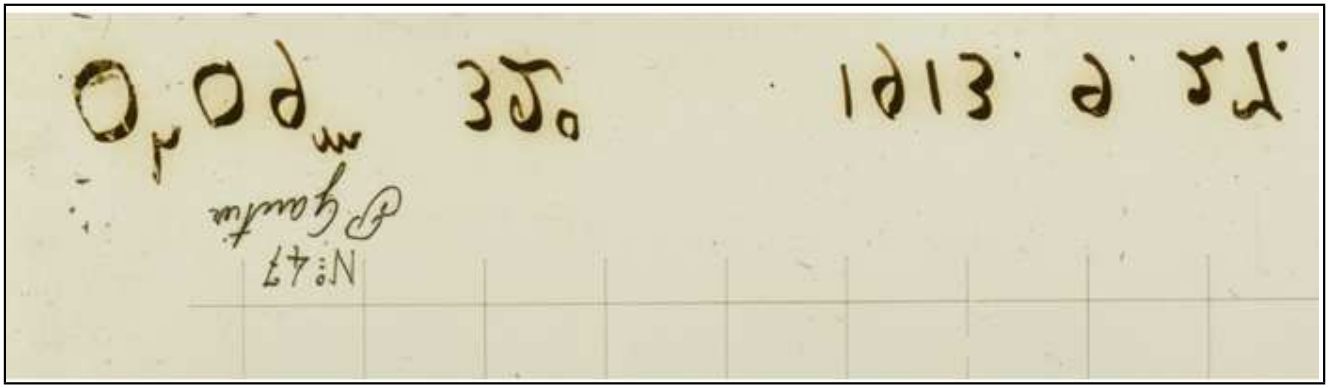
Astrographic plates

- the result of Carte du Ciel project;
- widely distributed among observatories all over the world;
- contain valuable data because of their age.

Astrographic maps

- paper copies of the astrographic plates;
- produced by photogravure on copper plates;
- we poses considerable data set of astrographic maps.

Astrographic plates



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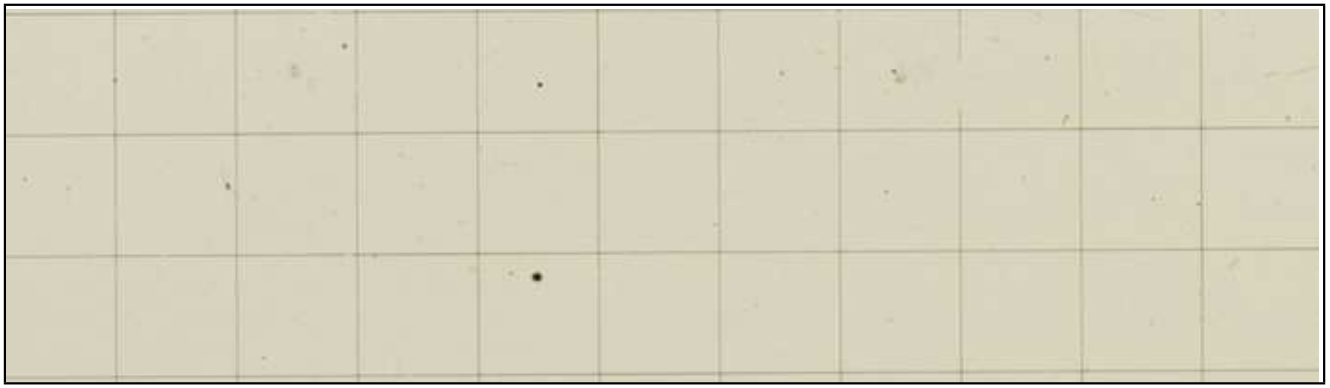

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General problem

The general goal of our research

★ Design methods and algorithms for automatic data extraction from digitized Carte du Ciel maps.

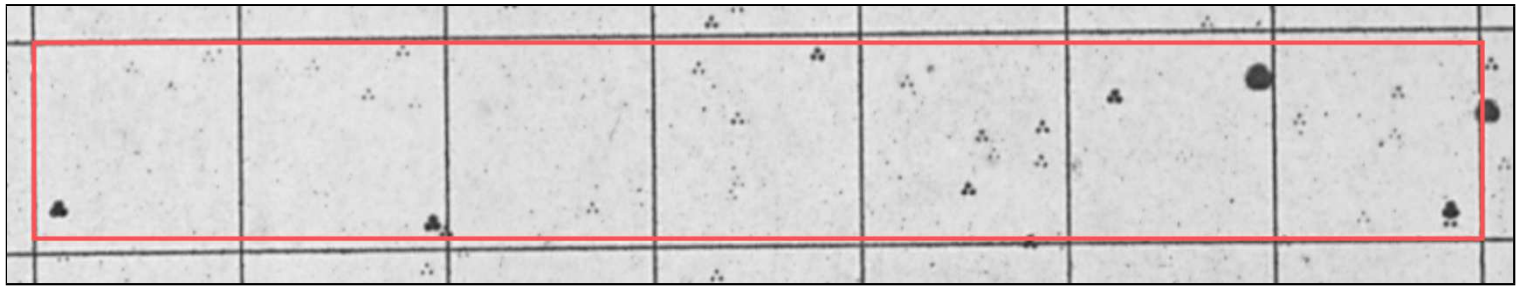
These methods incorporate:

- image quality enhancement, noise reduction;
- image segmentation and regions of interest extraction;
- automatic object recognition.

These methods are subject of the fields:

- digital image processing;
- pattern recognition.

In the current report



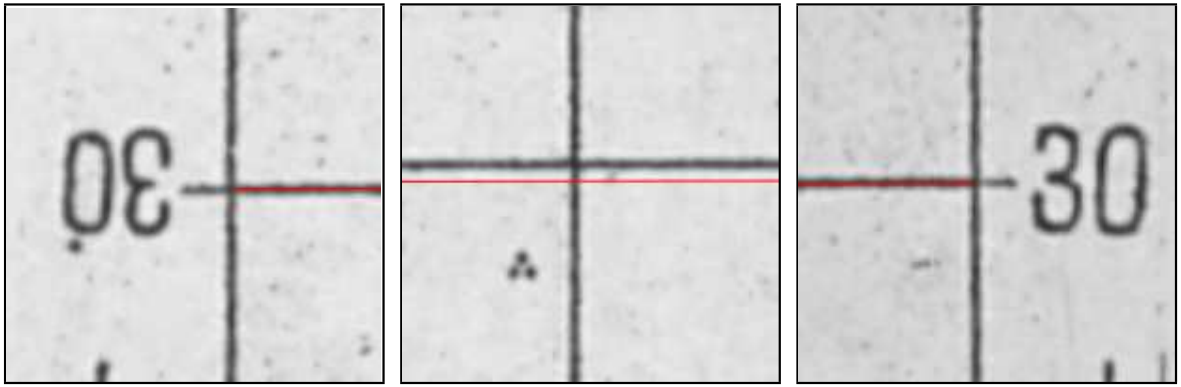
Stricture of the astrographic maps:

- coordinate system composed by orthogonal grid;
- theoretically images are horizontally adjusted;
- let us draw rectangle with top-left and bottom-right edges on the grid intersections.

Geometrical distortions in the maps:

- due to a slight rotation;
- due to to *paper surface curvature*.

Image de-warping



Atrographic map images are warped:

- due to the physical curvature of the paper;
- this introduces a *non-linear* geometrical distortion in the images;

Methods that remove or reduce such distortion:

- document image de-warping methods;
- usually they are an effort to improve OCR system.

In the context of OCR systems

In which applications the problem is considered?

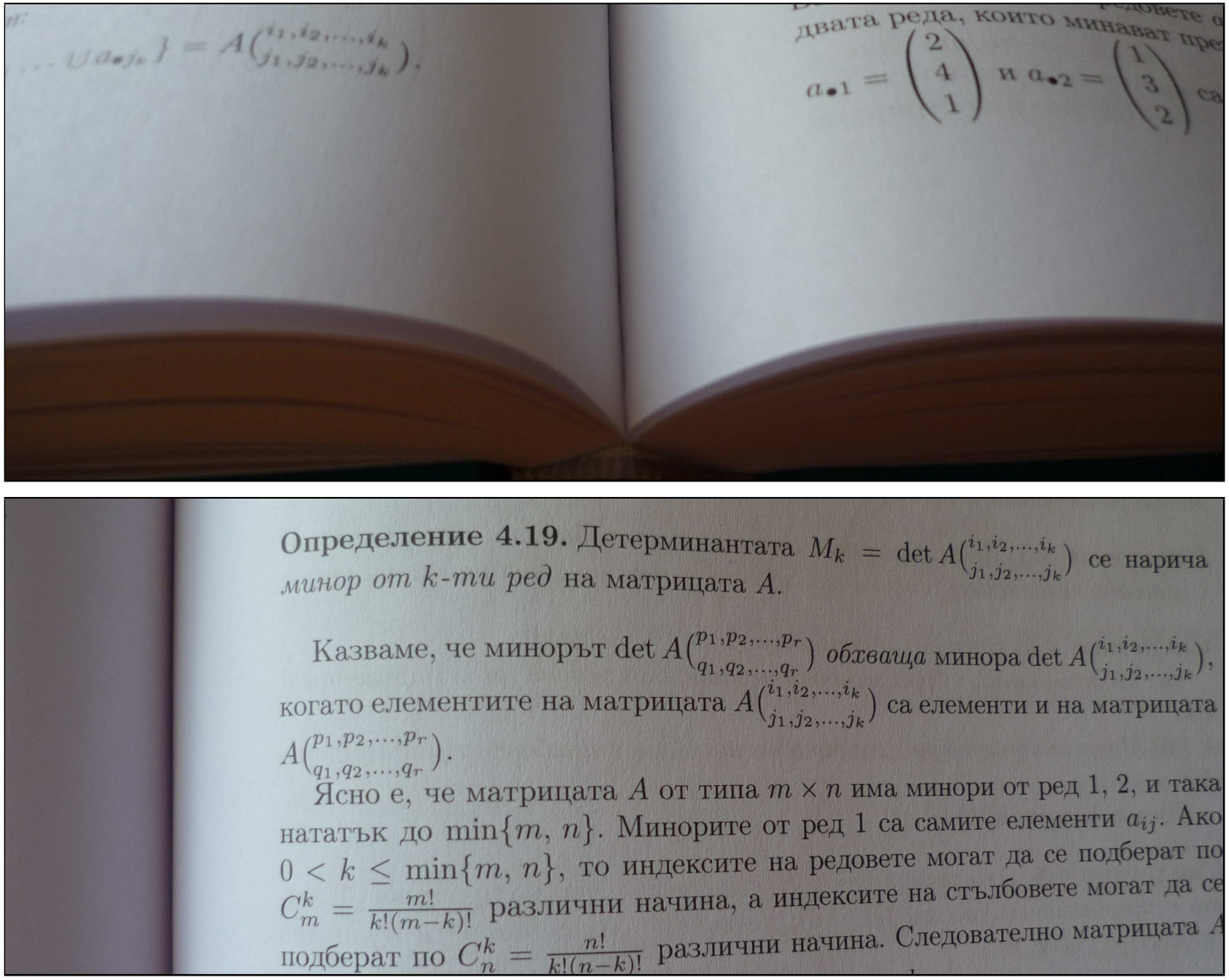
- Standard and commercial software do not consider page warping:
  - require input with a good quality;
  - straight textual lines.
- However, in many non-standard applications, de-warping can be an important stage.

In which case document image warping appear?

- Usually an image of a thick bound volume.
- The image can be acquired both by flat-bed scanner or a camera.

Document image warping is:

- ★ a non-linear geometrical distortion caused by the page curl;
- it can seriously affect the segmentation and recognition steps.



двата реда, които минават пре

$$a_{\bullet 1} = \begin{pmatrix} 2 \\ 4 \\ 1 \end{pmatrix} \text{ и } a_{\bullet 2} = \begin{pmatrix} 1 \\ 3 \\ 2 \end{pmatrix}$$

Определение 4.19. Детерминантата $M_k = \det A\binom{i_1,i_2,\ldots,i_k}{j_1,j_2,\ldots,j_k}$ се нарича *минор от k-ти ред* на матрицата A.

Казваме, че минорът $\det A\binom{p_1,p_2,\ldots,p_r}{q_1,q_2,\ldots,q_r}$ *обхваща* минора $\det A\binom{i_1,i_2,\ldots,i_k}{j_1,j_2,\ldots,j_k}$, когато елементите на матрицата $A\binom{i_1,i_2,\ldots,i_k}{j_1,j_2,\ldots,j_k}$ са елементи и на матрицата $A\binom{p_1,p_2,\ldots,p_r}{q_1,q_2,\ldots,q_r}$.

Ясно е, че матрицата A от типа $m \times n$ има минори от ред 1, 2, и така нататък до $\min\{m, n\}$. Минорите от ред 1 са самите елементи a_{ij}. Ако $0 < k \leq \min\{m, n\}$, то индексите на редовете могат да се подберат по $C_m^k = \frac{m!}{k!(m-k)!}$ различни начина, а индексите на стълбовете могат да се подберат по $C_n^k = \frac{n!}{k!(n-k)!}$ различни начина. Следователно матрицата A

- An open bound volume results in non-linear textual lines curl.

Existing applications

Standard/commercial and non-standard software:

- even though commercial software does not consider this problem;
- there are many attempts in no-standard applications;
- consider images taken by camera, and flat-bed scanners.

Images acquired by digital camera:

- popular cheep cameras, mobile phones cameras;
- historical that could be damaged by flat-bed scanners;
- valuable documents that cannot be transported.

In this survey we consider:

- State of the art techniques, described in more than 20 papers.
- Published in the period: 2000 – 2015.

Methods classification

According to image acquisition:

- images acquired using flat-bed scanners or other specialized equipment;
- images acquired using digital cameras.

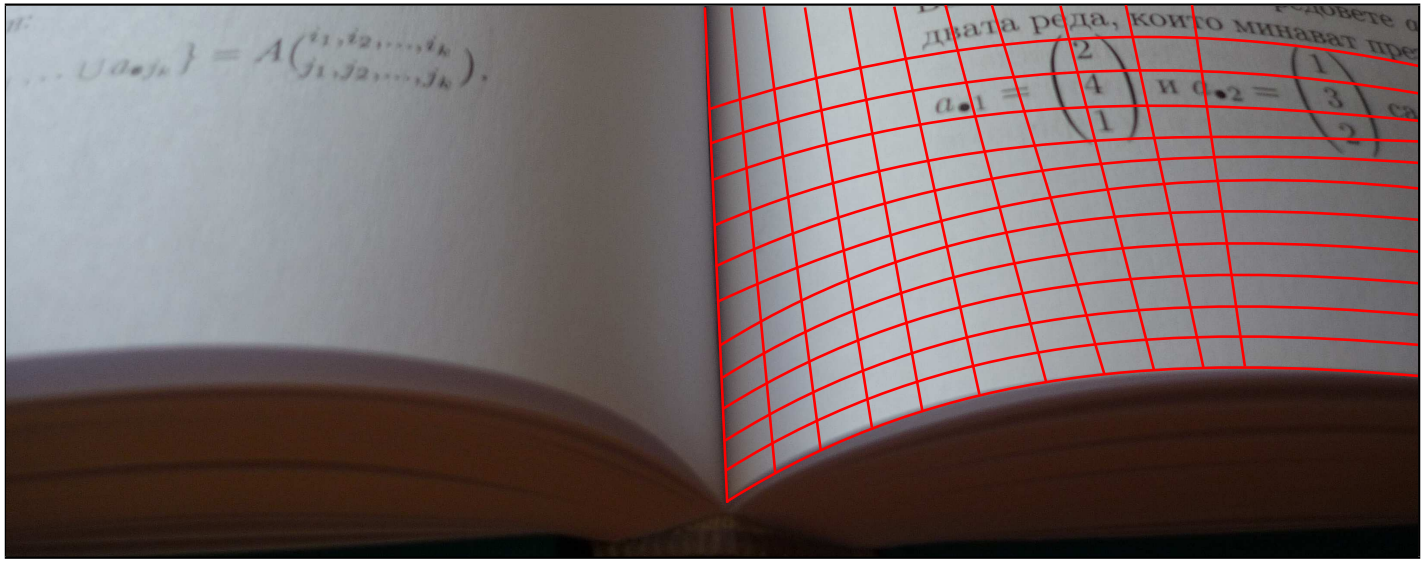
According to the hardware used:

- methods that require additional specialized equipment;
- methods that relay on the image only.

According to the approach:

- 3D page shape reconstruction;
- 2D image processing techniques.

3D page shape reconstruction methods



The goal of these methods:

- develop reconstruction of the curled page surface in 3D;
- based on the 3D page model, create a de-warping procedure.

Optical model:

- many of these approaches rely on a priori knowledge for the optics.

Shape-from-shading techniques

These methods:

- use the shading information to recover the page surface;
- for example, the works proposed in [14], [13].

In [14] two models for shape reconstruction:

- *geometric model* and *optical model*;
- the original text image is approximated based on these models.

- Geometric model:

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

- Optical model:

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

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distance between scanning plane and page surface

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slant angle of the book surface at y_j

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angle between light source direction and normal of the scanning plane

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pixel values corresponding to the background

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global maximum pixel value

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parameter from calibrated image

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Geometrical shape assumption based methods

These methods:

- rely on some assumption for the geometrical shape of the page curvature;
- [11] and [5] assume *cylindrical shape*;
- or the shape may be approximated by an experiment: [8].

- Keeping the notation from [8], de-warping process can be described:

$$f(x', y') = T\left(f(x, y)\right)$$

The mapping between the rectified image and distorted image:

- in [11] is a matching procedure based on projective model;
- in [5] is used the pointwise bilinear resampling [1];
- in [8] is extracted by the experiment.

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Cartesian coordinate system of the de-warped surface

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Segmentation based methods

These methods:

- use extracted text lines to build curved page surface;
- based on the assumption that original text lines are straight;
- such method is [10].

Text lines segmentation in [10]:

- a modification of the RAST algorithm;
- RAST is a method for geometrical model fitting;
- given a set of symbols bounding boxes, an optimal base line is discovered.

- The 3D model in [10]:

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

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image point $p = (u, v)$ is projected on the 3D point p'

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a value to compensate for the perspective projection

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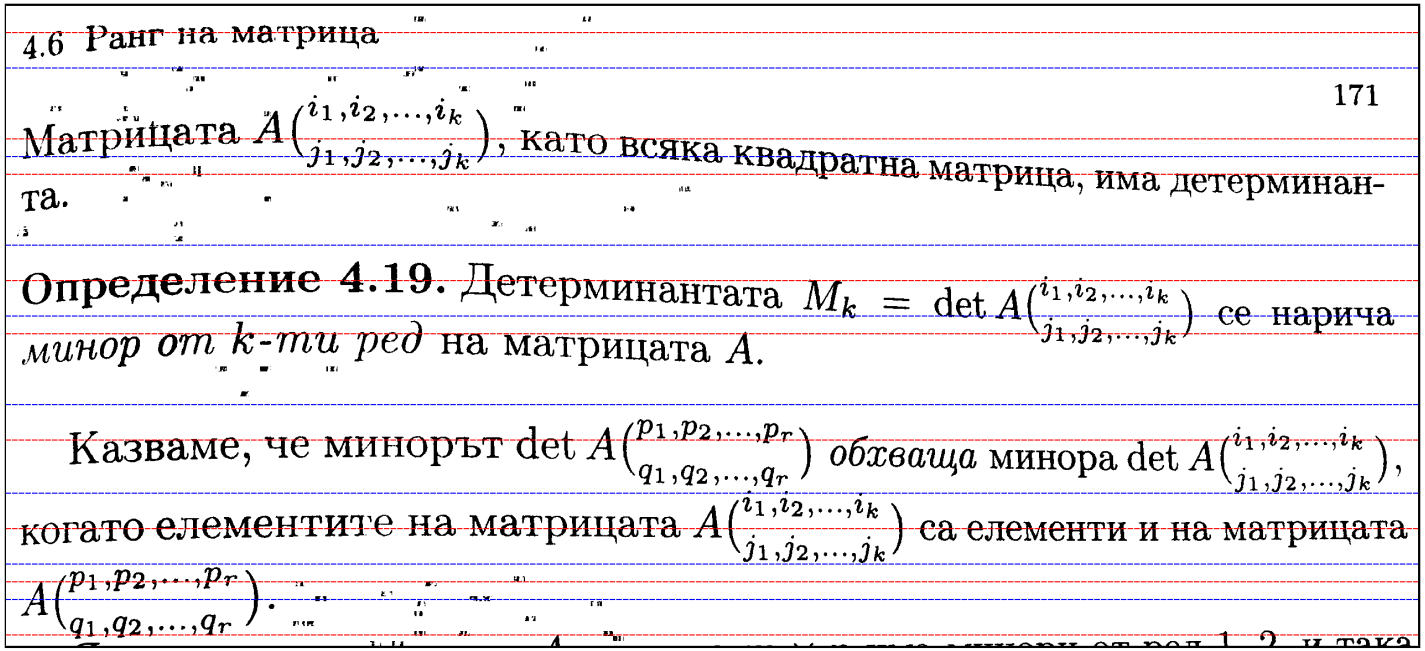
2D image processing techniques



4.6 Ранг на матрица

171

Матрицата $A\binom{i_1,i_2,\ldots,i_k}{j_1,j_2,\ldots,j_k}$, като всяка квадратна матрица, има детерминанта.

Определение 4.19. Детерминантата $M_k = \det A\binom{i_1,i_2,\ldots,i_k}{j_1,j_2,\ldots,j_k}$ се нарича *минор от k-ти ред* на матрицата A.

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A category of methods based on 2D image processing:

- do not rely on a priori knowledge about camera parameters, physical shape of the curl;
- based on features extracted from the image content.

★ For astrographic maps processing, maybe this category of methods is more interesting.

Text lines estimation

Most commonly used feature extracted from the image content:

- basic assumption is that text lines are straight in the original document;
- the curvature of the lines gives the curvature of the entire image.

In Kakumanu [4]:

- RANSAC (random sample consensus) method.

In Schneider [6]:

- projective profiles and Sobel filter.

In Zandifar [12], Gatos [3]:

- bottom-up approach by firstly discovering the connected components like symbols and words.

De-warping based on polynomials and splines

Polynomials and splines are used to model text lines

- text lines are represented: [6], [12], [7];
- sometimes the gaps between the lines are used instead of the lines themselves: [2];
- in some works, only top and bottom lines are used: [12], [7].

De-warping is performed based on the polynomials/splines representation

- in [6], vector field is used to map the curved surface to flat image;
- in [12], [7], blending top and bottom lines functions;
- in [2]: optimal fitting problem, minimization of the function J.

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

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number of splines that represent gaps between lines

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evaluate difference between spline model and actual warp. $f = 0$ if spline is fitted in a gap

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

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$\theta_i = (\alpha_i, \beta_i, \gamma_i)$ represents the i-th spline

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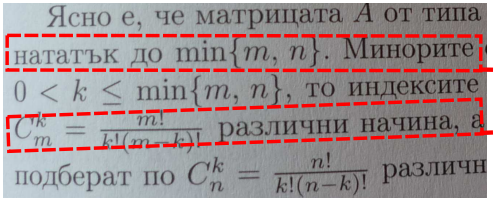
positive constant

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

De-warping based on other geometrical models


Ясно е, че матрицата A от типа
нататък до $\min\{m, n\}$. Минорите
$0 < k \leq \min\{m, n\}$, то индексите
$C_m^k = \frac{m!}{k!(m-k)!}$ различни начина, а
подберат по $C_n^k = \frac{n!}{k!(n-k)!}$ различн

Horizontal and vertical vanishing points

- used mainly to remove the *perspective distortion*, [4];
- page curl is corrected line-by-line using geometrical transformations.

Image mosaicking

- in [9] the input is two images of the same document;
- the method constructs single image with reduced curvature.

Translation, scaling and rotation

- geometrical transformations on individual words or symbols;
- transformations to reconstruct document lines: [4], [3], [9].

Discussion

From OCR systems point of view

- Many of the proposed methods duplicate the segmentation stage.
- If we can segment correctly the document lines, why do we have to de-warp the image?
- Sometimes individual words and characters are not de-warped, but they are transformed to form straight lines.

From astrographic maps processing point of view

- Most probably a 2D image processing approach is applicable.
- A good features in the image content: *the orthogonal grid*.
- Image data is very sensitive.

Thank you!

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