

# Browsing Through Closed Books: Fully Automatic Book Page Extraction from a 3-D X-ray CT Volume

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## Introduction

### Historical Document Analysis by Non Destructive Testing

For many historical documents, the standard procedure of using a book scanner is not applicable, because the document would get damaged by the page-turning process.

A lot of those old manuscripts where written with iron gall ink, which is used since the 5th century until present [1]. This kind of ink consists of metallic particles. When performing a 3-D X-ray CT scan, those metallic particles allow us to see the writings as their X-ray absorption differs from the paper's [2].

### Challenges

Fig.1. shows that a single page can not be easily investigated due to its waviness in the volume. A segmentation by hand is very time consuming.

➤ Need of an automatic algorithm for extraction of pages [3].

## Materials and Methods

### Book Model

- 22 pages of handmade paper, 150  $\mu\text{m}$  thickness
- Iron gall ink writings
- Leather cover

### 3-D X-ray CT Scan and Reconstruction

- Cone beam geometry, book upright
- 3-D CT scan with 800 projections over 360°
- X-ray energy 50 kVp, detector pixel size 44  $\mu\text{m}^2$
- FDK reconstruction, 44  $\mu\text{m}^3$  voxel size

### Page Extraction Algorithm

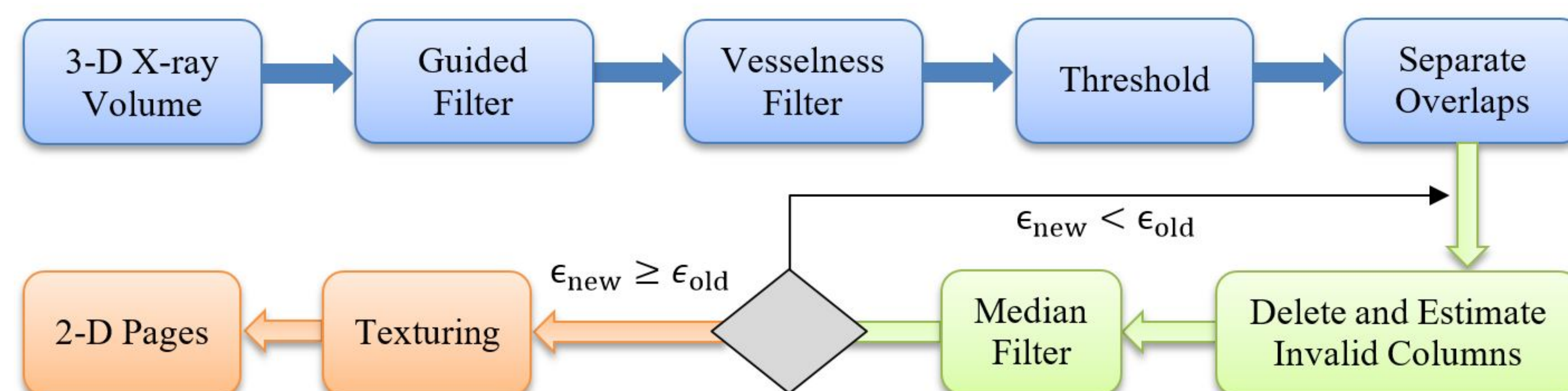


Fig.2. 3-D Volume Processing Pipeline demonstrating the process of the 2-D page mapping.

Fig.2. shows the pipeline of our algorithm based on an earlier approach [4]:

- The blue boxes denote the pre-processing steps consisting of image denoising, Vesselness [5] filtering in  $xz$ -direction and thresholding. The overlapping pages are split according to Fig.3. resulting in a binary page mask ( $air = 0$ ,  $page = 1$ ).
- The green boxes denote a process that is iterated until a stop criterion is reached. Initially, the number of pages  $N$  are estimated. For every column in  $xz$ -direction the number of pages are counted and those that are not equal to  $N$  are set to '0'. The result is Median filtered to close the arising gaps. The steps are repeated until the new result differs only slightly from the old.
- The resulting binary mask is multiplied with the original volume such that the air is '0' and only the grey values of the pages are left. Afterwards, a texturing step (Fig.4.) is performed for every single page extracting the maximal value along the centerline's normal. Finally, the extracted 2-D pages can be investigated.



Fig.1. Volume slice of micro-CT scan.

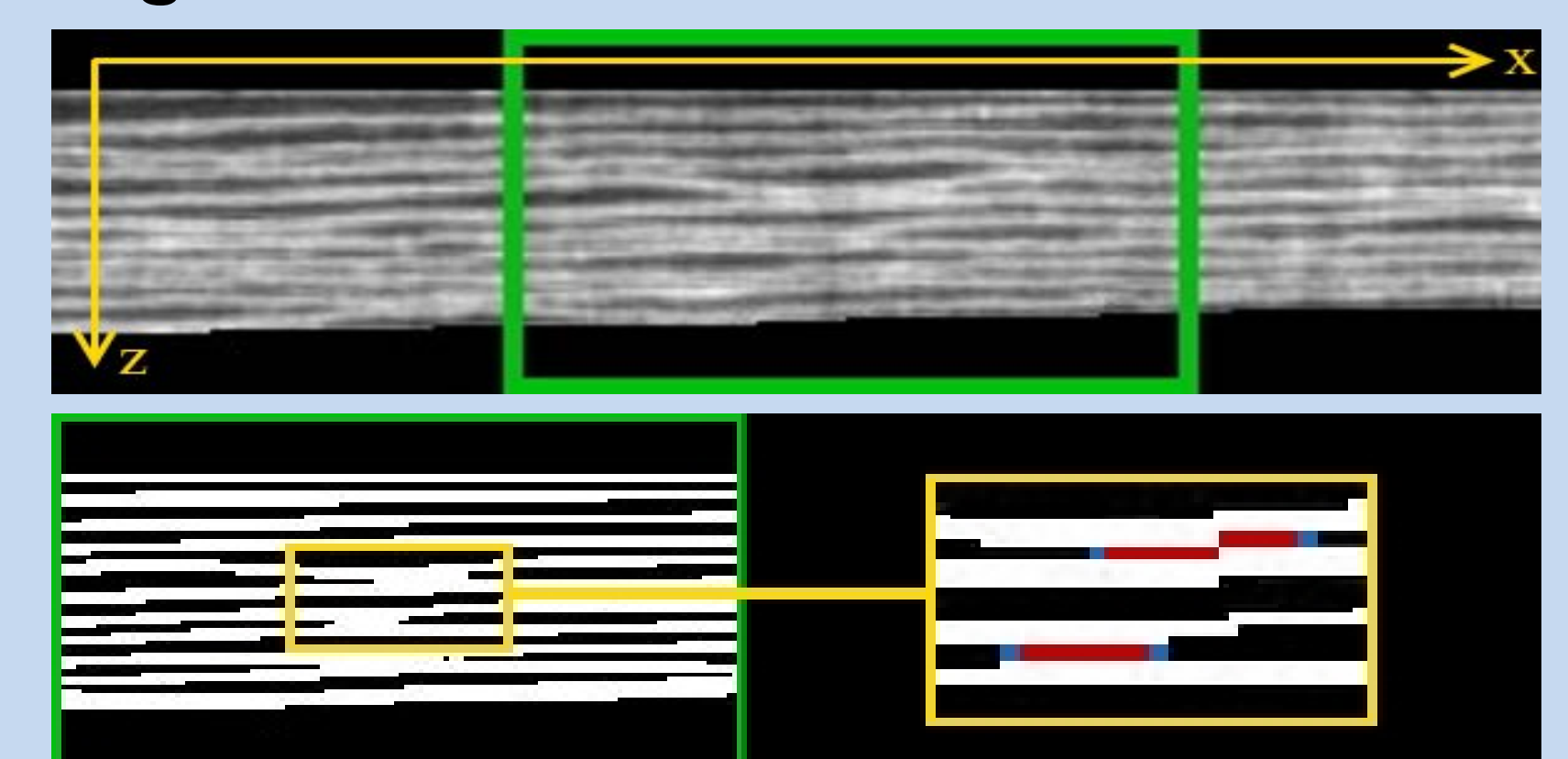


Fig.3. (Top) Unfiltered  $xz$ -direction volume slice. (Bottom) Page separation: The binarized page is split where an overlap is detected.

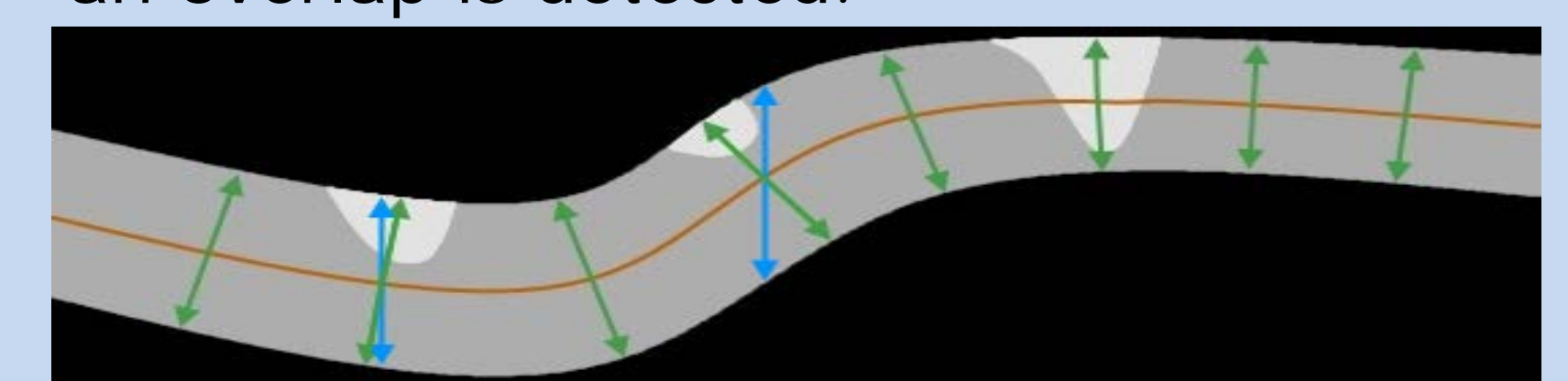


Fig.4. Texturing: The normal (green) along the page's centerline (orange) is calculated and the maximal value stored.

## Results and Discussion

- Fig.5. shows three exemplary original pages and the 3-D reconstructed and extracted 2-D mapped pages.
- All 22 pages of the volume were extracted properly. Also tests on other scanned books showed similar results.
- The algorithm converged after 24 iterations resulting in a total computation time of around 5.5 minutes.
- A post-processing step for image denoising (guided filtering) and unsharp masking can improve quality.

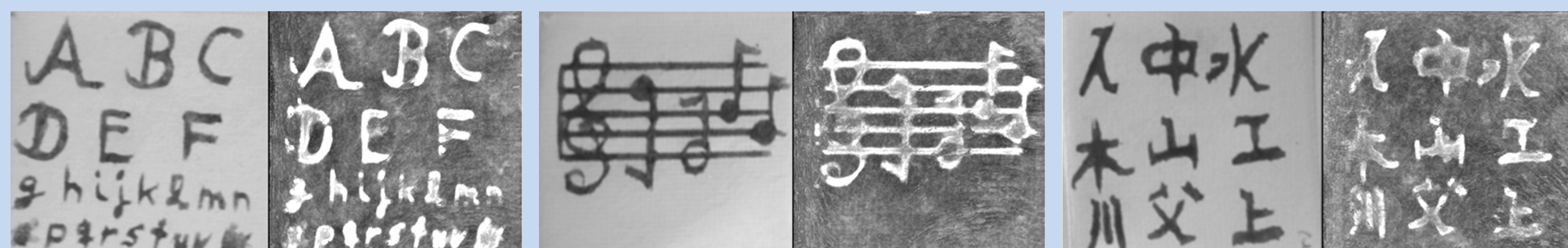


Fig.5. Three exemplary original pages (left) and the 3-D reconstructed and extracted page (right) from the closed book. The writings and drawings are clearly visible such that a specialist would be able to further investigate the document.



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## Conclusions and Outlook

- Manuscripts can be scanned by 3-D X-ray CT without opening or page-turning.
- Proposed algorithm extracts and 2-D maps all pages.
- Tested also for extreme cases (wavy and thin pages).
- No user interaction needed and low computation time.

Future work:

- Find the best scan parameters, best reconstruction algorithm and take real historical documents.

## References

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