E-MRS
European Materials Research Society

Spring Meeting 2015

X-RAY COMPUTED TOMOGRAPHY FOR VIRTUALLY UNROLLING DAMAGED PAPYRI

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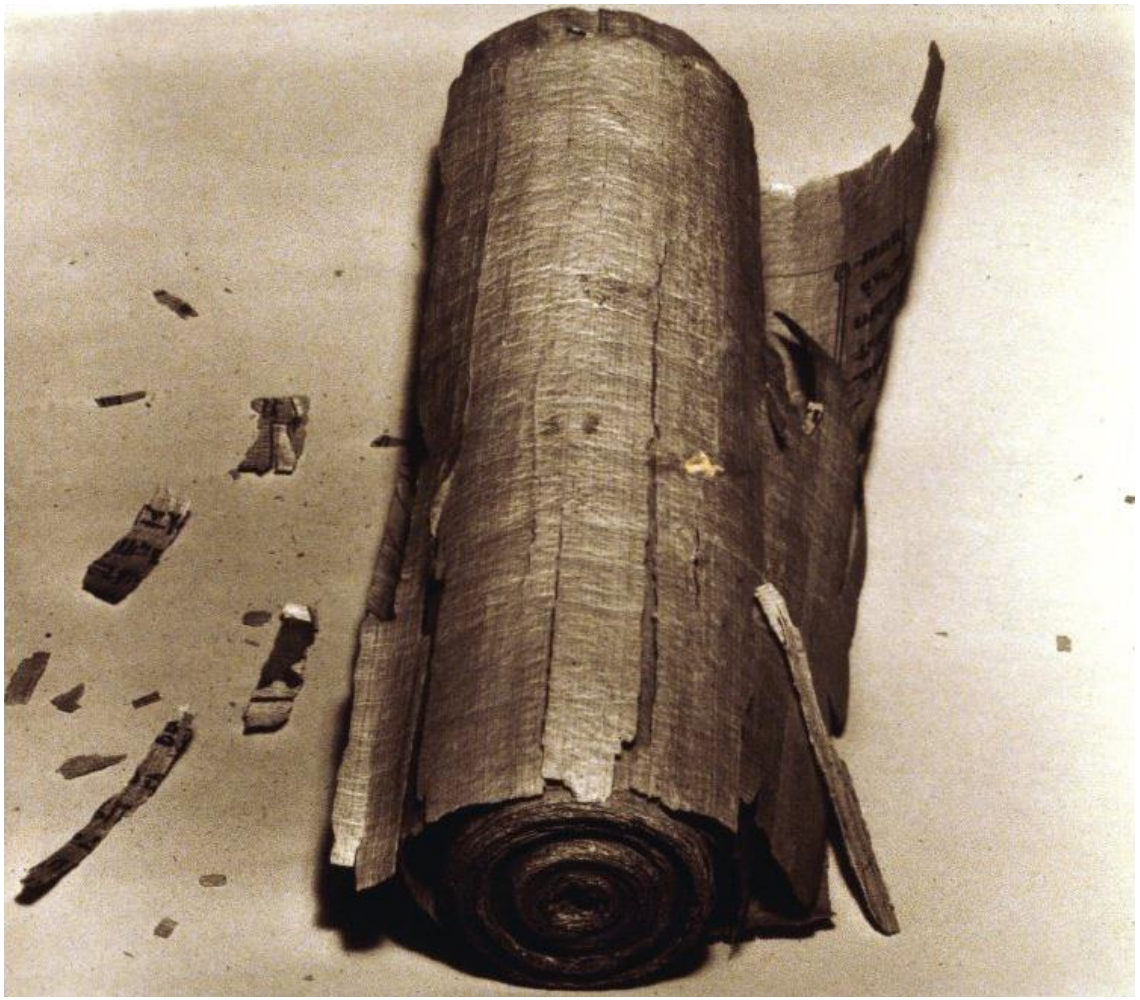
Introduction

- The regular format for ancient works of literature was the papyrus roll.
- Old papyri are the substrates of very important historical information.
- Papyrus degradation is often very hard so that physical unrolling is sometime absolutely impossible.

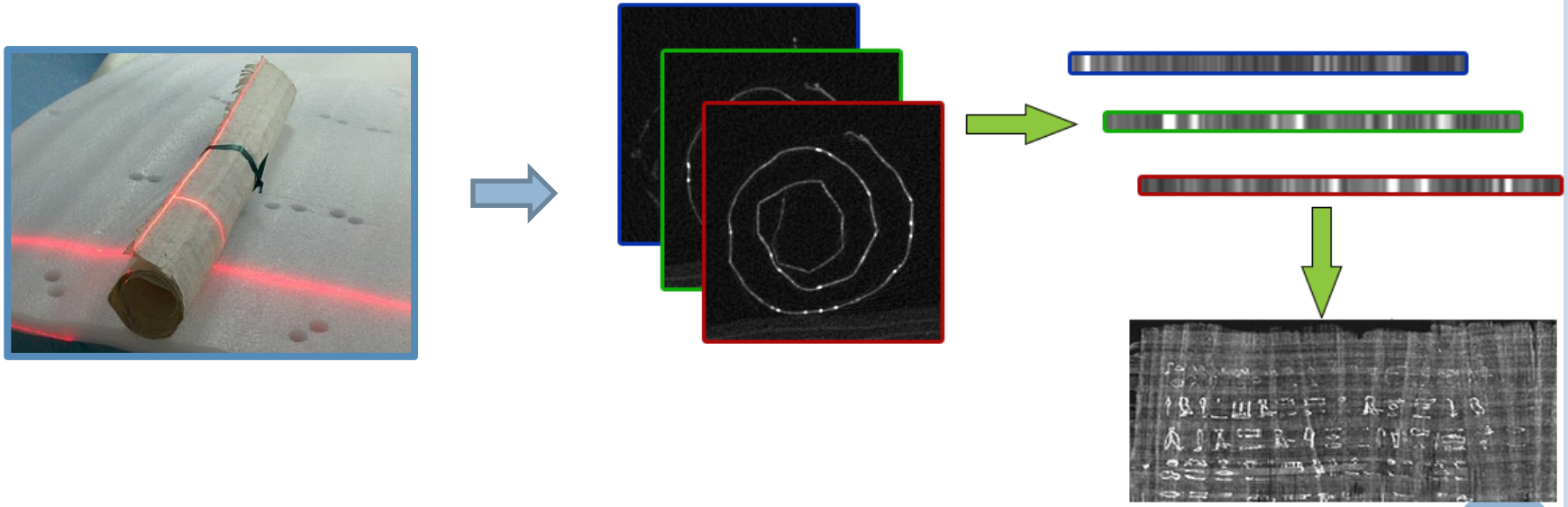
Example



Book of the Dead of Panedjem II, Papyrus before unrolling. - British Museum

Introduction

- We propose a method for virtual unrolling of this archaeological artifact.



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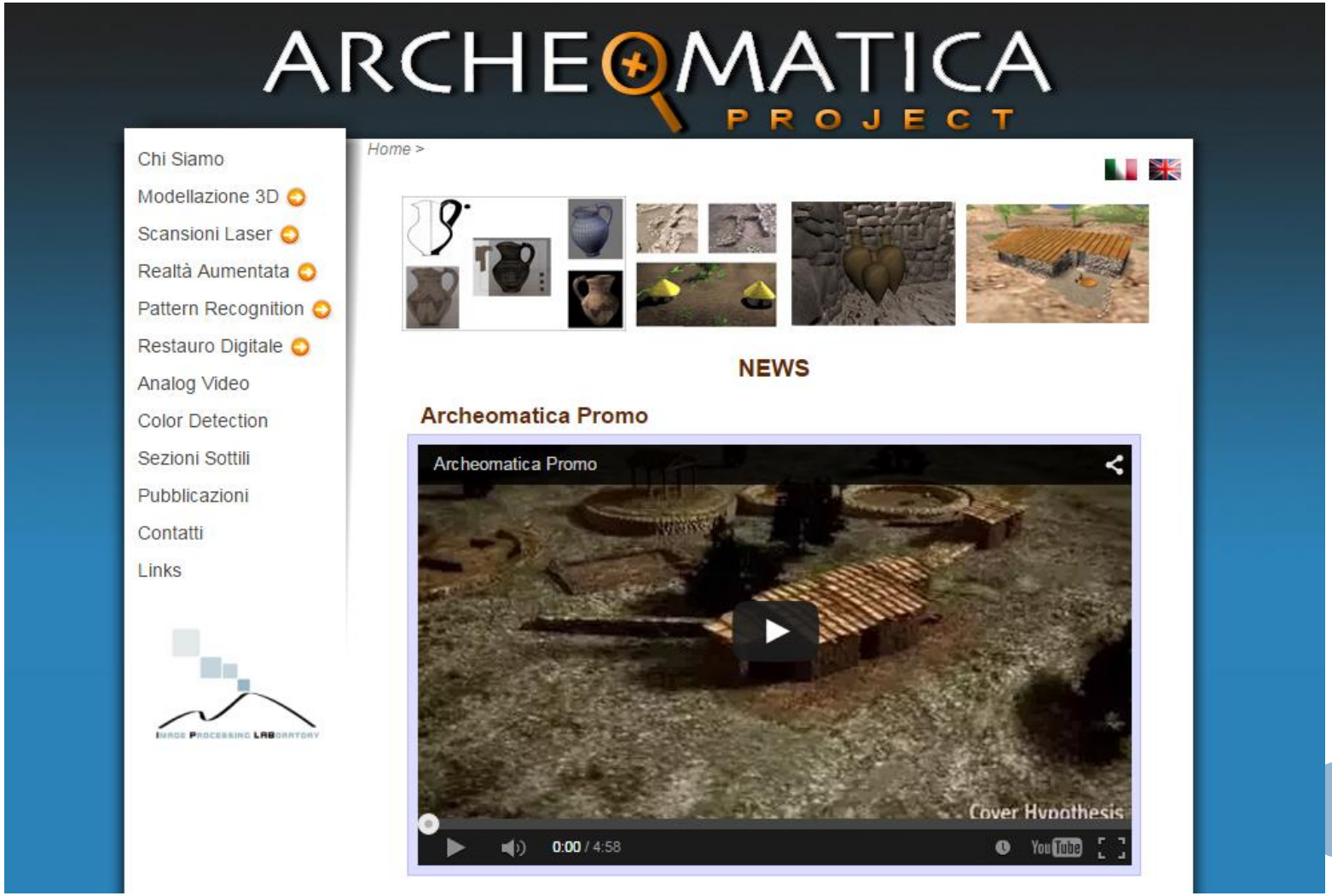
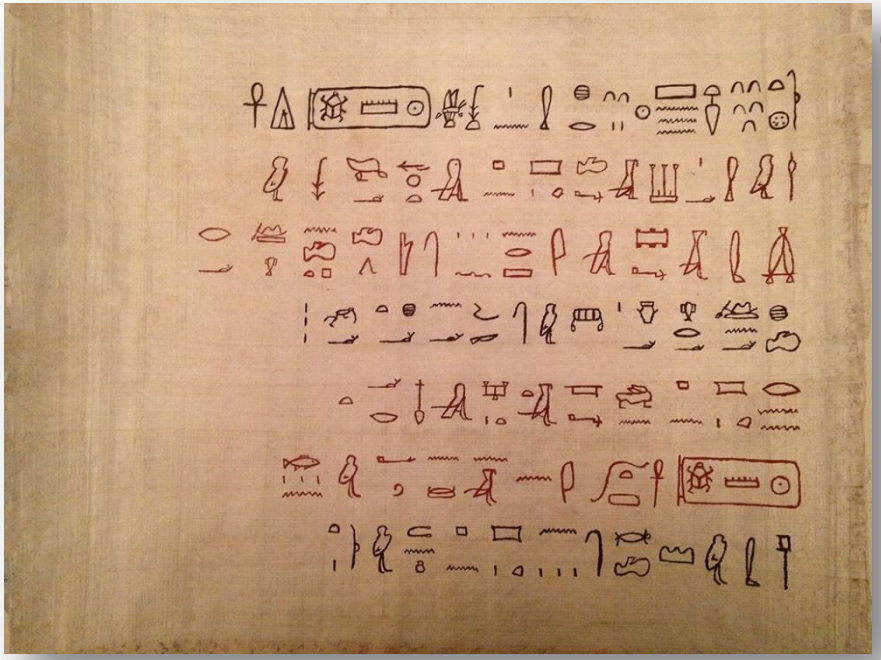


CASE-STUDY PAPYRUS

- To cope with the problem, a realistic model was made for the X-ray investigation.
- This model has made by the original method described by Plinius the Elder.
- Ireports a hieroglyph inscription of Thutmosis III,.
- The pigments and the binders are compatible with the Egyptian use (ochres with natural glue).



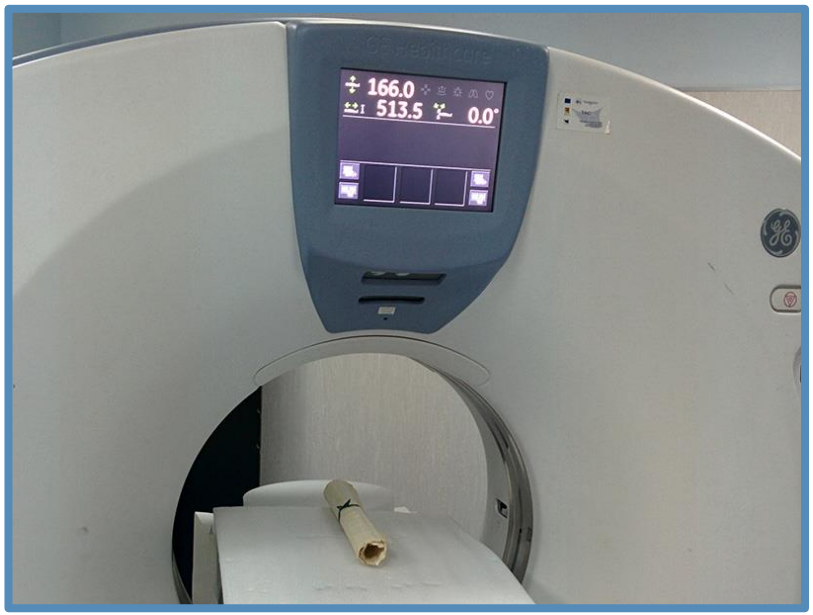
PROPOSED FRAMEWORK

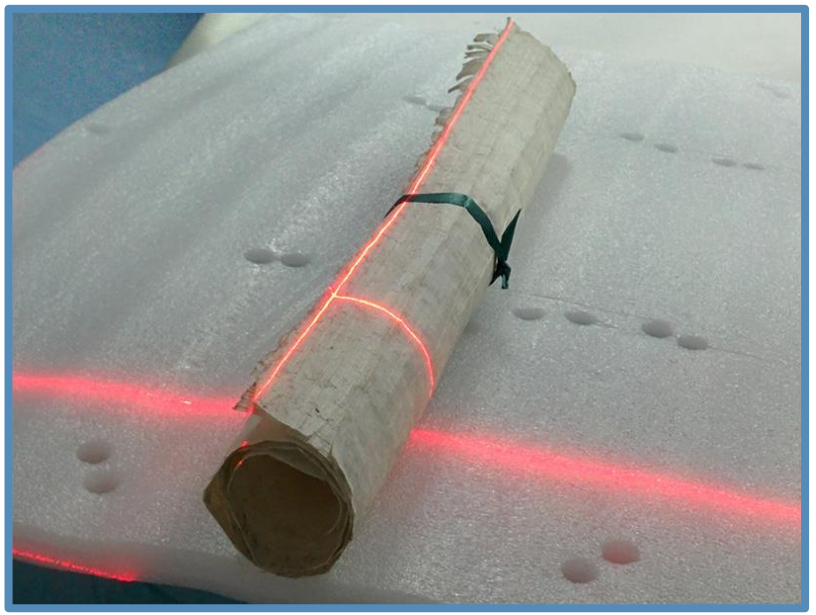
- Using Computed Tomography to obtain a stack of papyrus "slices".
- Handling these tomography images using Digital Image Processing techniques.
- Detecting papyrus cross-section through mathematical morphology and statistical consideration.
- Virtual Unrolling through merging operation of processed slices.

X-RAY COMPUTED TOMOGRAPHY

X-ray computed tomography is a technology that uses X-rays to produce tomographic images, or 'slices', of a scanned object, allowing to see inside the object without cutting.

These devices are widely exploited in clinical field.





Employed Hardware

- a **GE Optima 660 64**, was used to obtain a stack of tomographic slices.
- minimal isotropic spatial resolution of this device is 0.35mm and it can provide until to 128 distinct projection measurements per rotation.

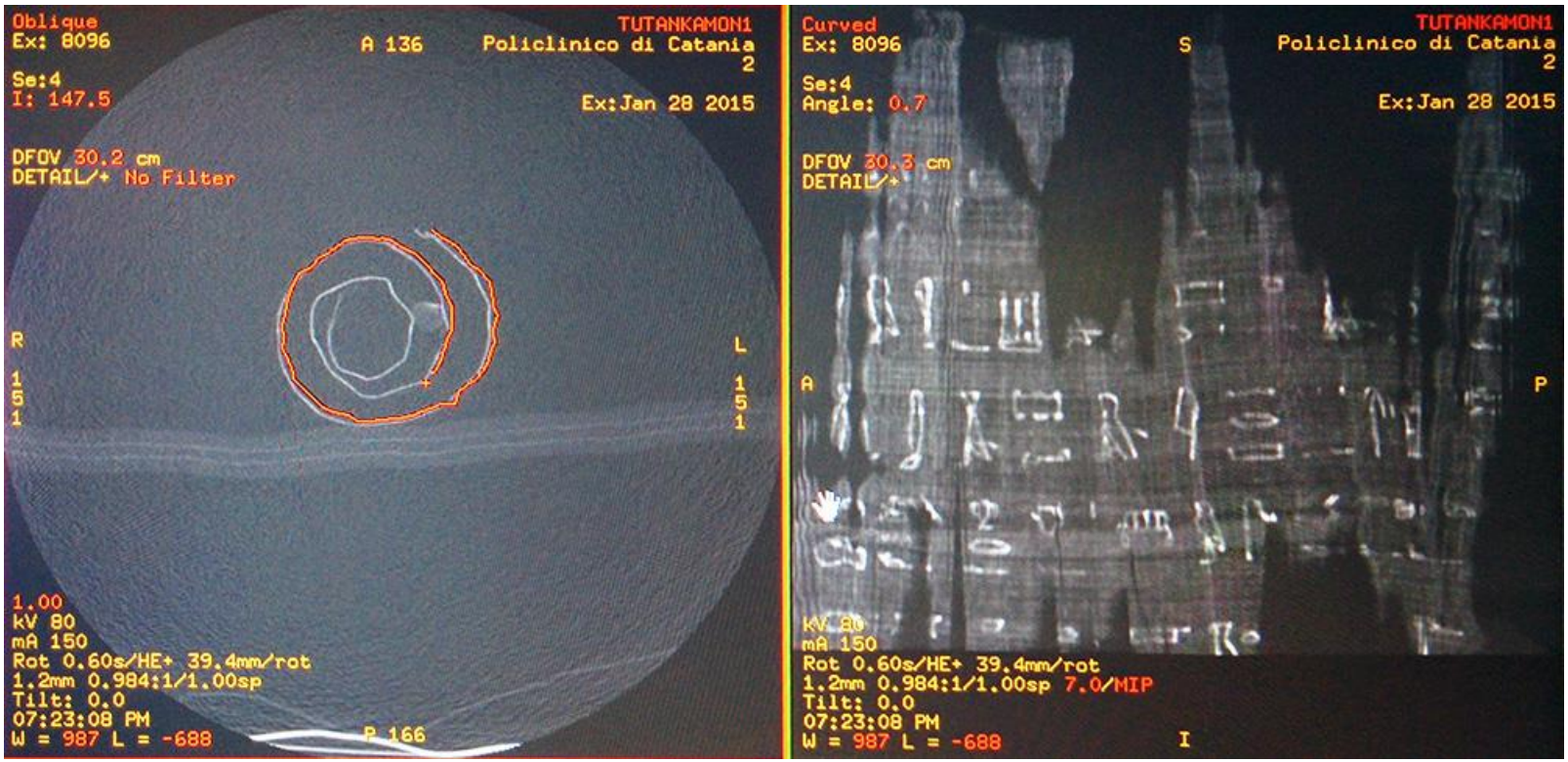
Device Settings in this work

Slice Thickness: 0,6 mm
Rotation Time: 0,8 s
Pitch: 0,98
Tilt: 0.0

Pixel Matrix: 512x512
kV: 80
mA: 50
sFOV:50

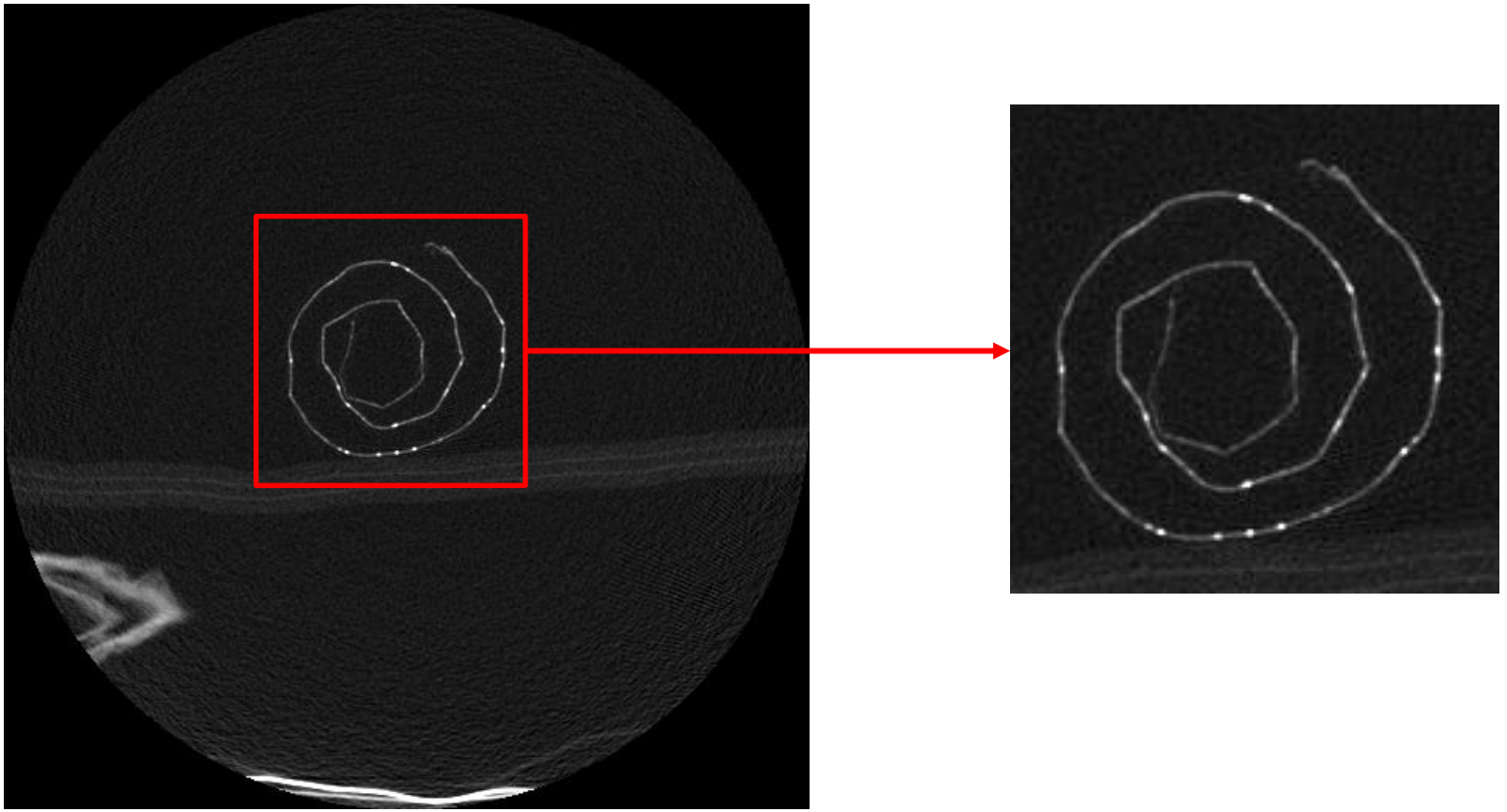
GEO OPTIMA SOFTWARE

An application software provided with CT-Device, allows to perform a roughly and user guided unrolling. This strategy exploits the Maximum Intensity Projection (MIP), which is used for human body-parts 3D reconstruction.



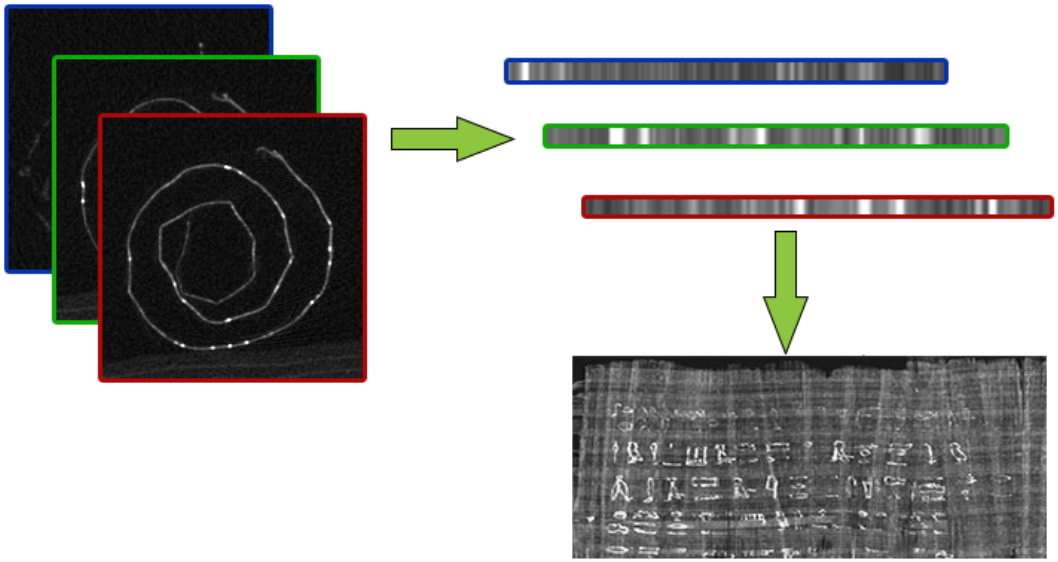
CT-Device output

The output of XCT devices is a group of N slices. The size of each of them is 512 × 512. The papyrus cross-section appears as a spiral on the center of image, so we can crop it.



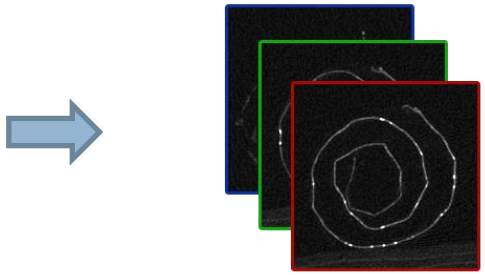
IDEA

- To solve the problem each of N papyrus cross-section should be automatically identify.
- So an array of ordered pixels for each slice must be built.
- By stacking all pixels arrays, the final papyrus image is obtained.

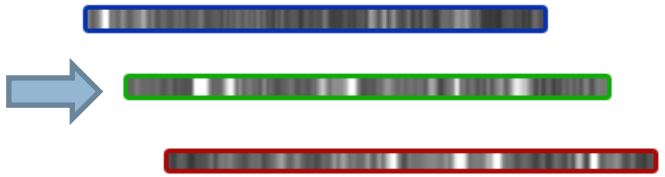


PROPOSED ALGORITHM

1. **Good slice selection**: because of noise and sheet overlap, it is hard identify each papyrus cross-section. Hence, we use a single "good" slice to reconstruct the entire papyrus.



2. **Good slice reconstruction**: the selected good slice is analyzed to sort spiral pixels. In this phase, a user selects the start point and the final point of papyrus section.



3. **Virtual unrolling:** using information of the good slice coordinates array, the other slices pixels are detected.

Step 1: Slice Selection

A “good” slice is an image which allows to detect almost the entire papyrus cross-section, through a rough segmentation.

It should not contain papyrus sheet overlap in order to minimize errors.

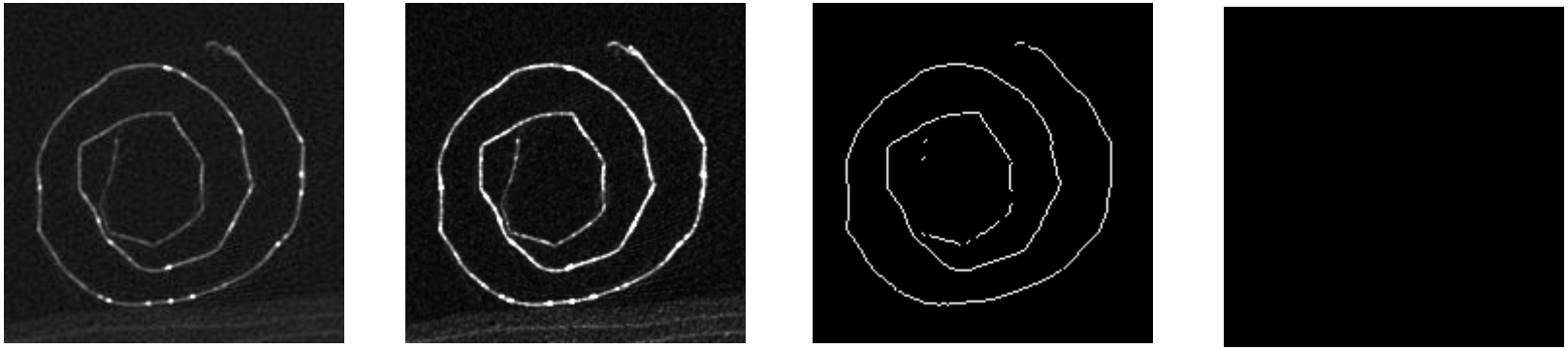
How to satisfy these two criteria?

1. We should select an image with about an average number of pixel after a rough segmentation. This strategy ensure many information and few noise. The rough segmentation is performed by morphological **skeletonization**.

2. To identify sheet overlaps, **branch-points morphological operator** is used. We should select an image with a minimum number of branch-points.

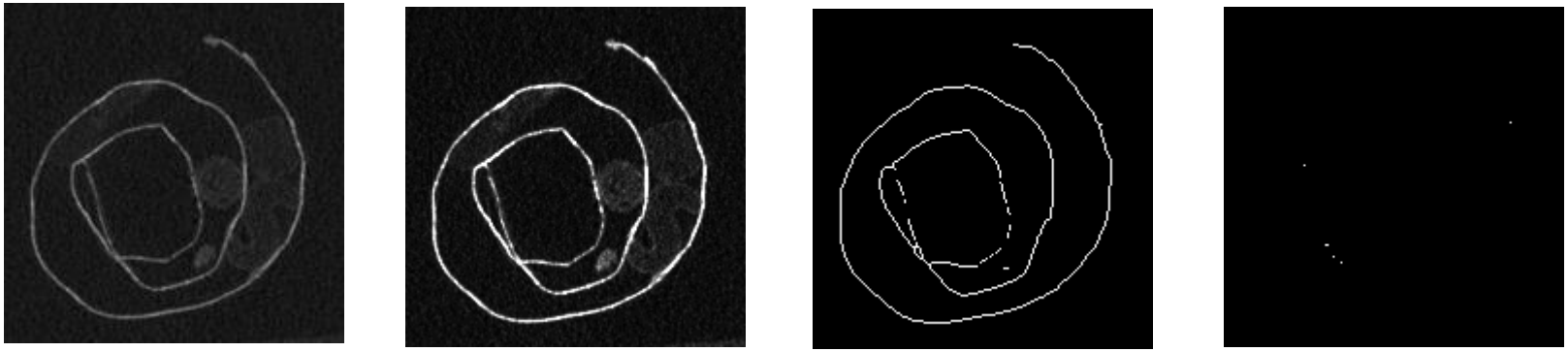
Step 1: Examples

Original → Enhancement → Skeleton → Branch-points



GOOD SLICE

Original → Enhancement → Skeleton → Branch-points



BAD SLICE

STEP 2: GOOD SLICE RECOSTRUCTION

When a good slice is chosen, its cross-section can be rebuilt.

- User selects start point and final point.

- A 3×3 window scans the skeleton image. In the 8-neighbourhood of last identified pixel the next is selected.

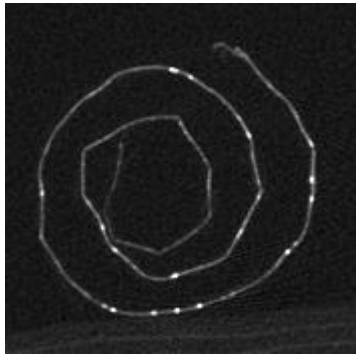
- If a "break" on the skeleton is reached (morphological end-point) then, the 3×3 windows scans the original image in order to find the max intensity pixel. A probability mask take into account the direction of last window movement.

Step 2: Example

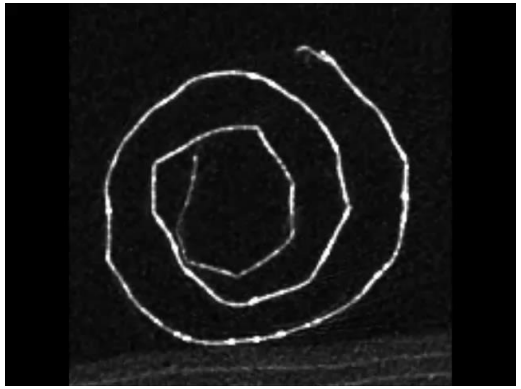
Skeleton

End-points

Original



Result



STEP 3: PAPYRUS RECONSTRUCTION

The last step is the papyrus virtual unrolling.

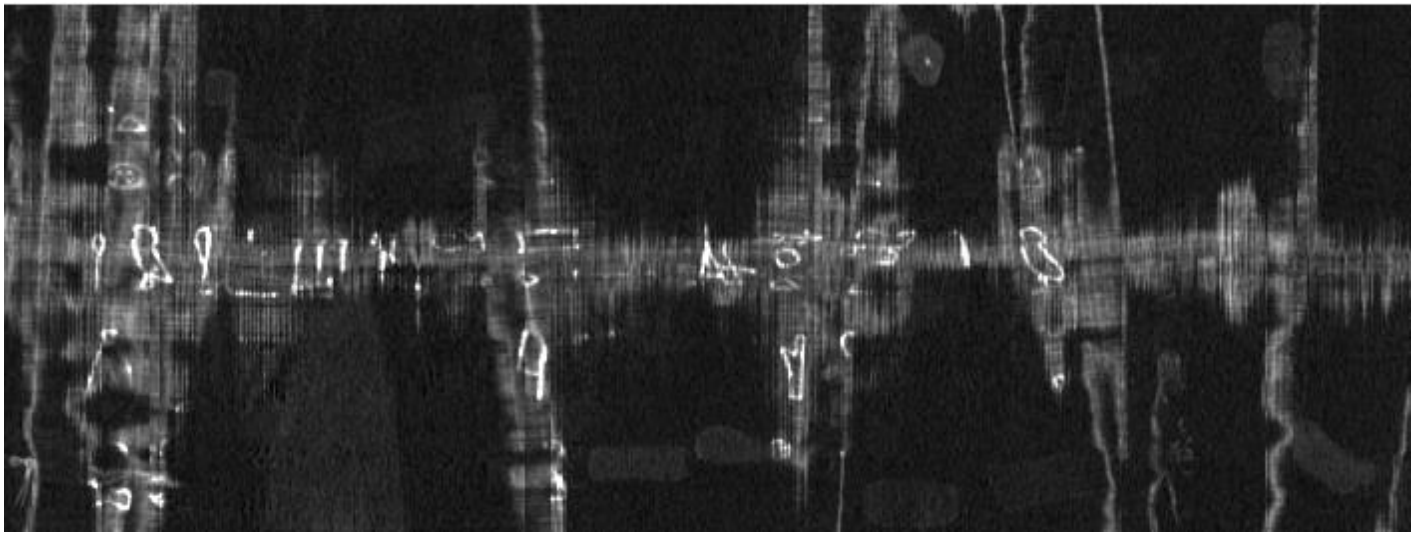
- For each slice we select the pixels whose coordinates are stored in the vector of good slice visited points.

- For each coordinate, the pixels of maximum intensity along the direction of the gradient is chosen. Indeed sheet and text of image have an higher intensity than background.

- In this way, we obtain a string of pixels for each slice. By stacking all this string, we get the image of the papyrus rolled out.

WRONG RECONSTRUCTION

If you don't choose the pixels of maximum intensity along the direction of the gradient, there are many missing information.



Experimental results

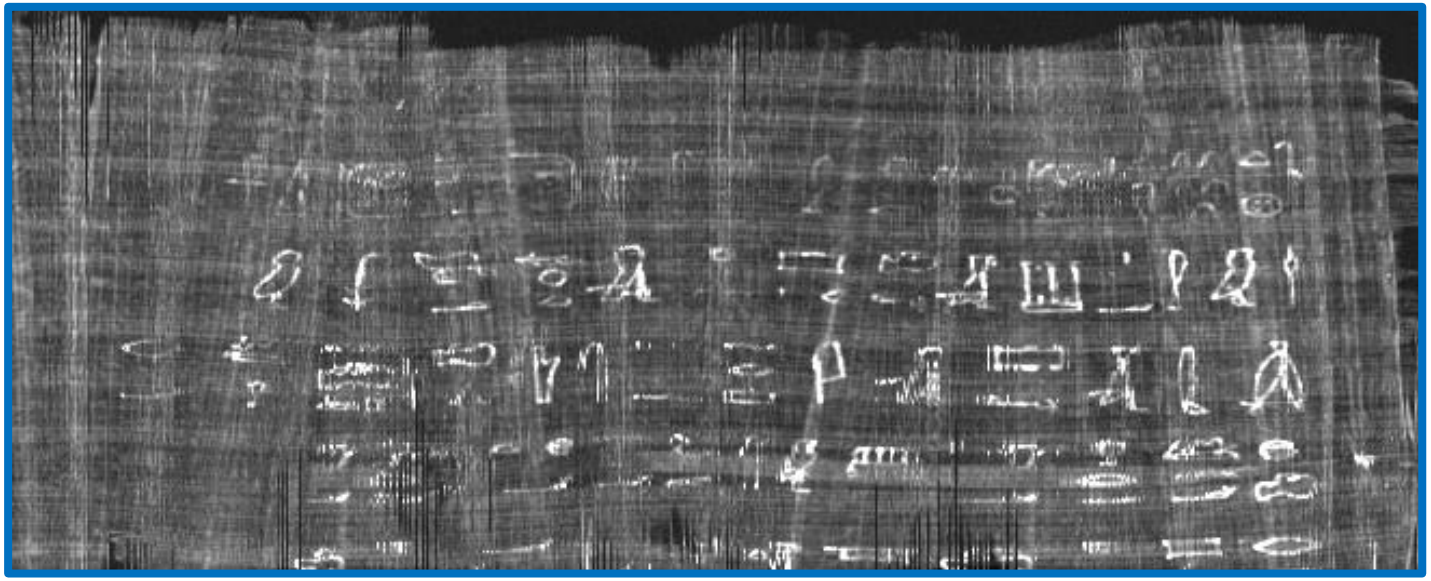
In our case study, a group of 259 slices of a single XCT scan has been analyzed.

- In the step 1, the 122th slice was automatically selected according the discussed criteria. It has 0 branch-points and a number of skeleton pixels around the average.

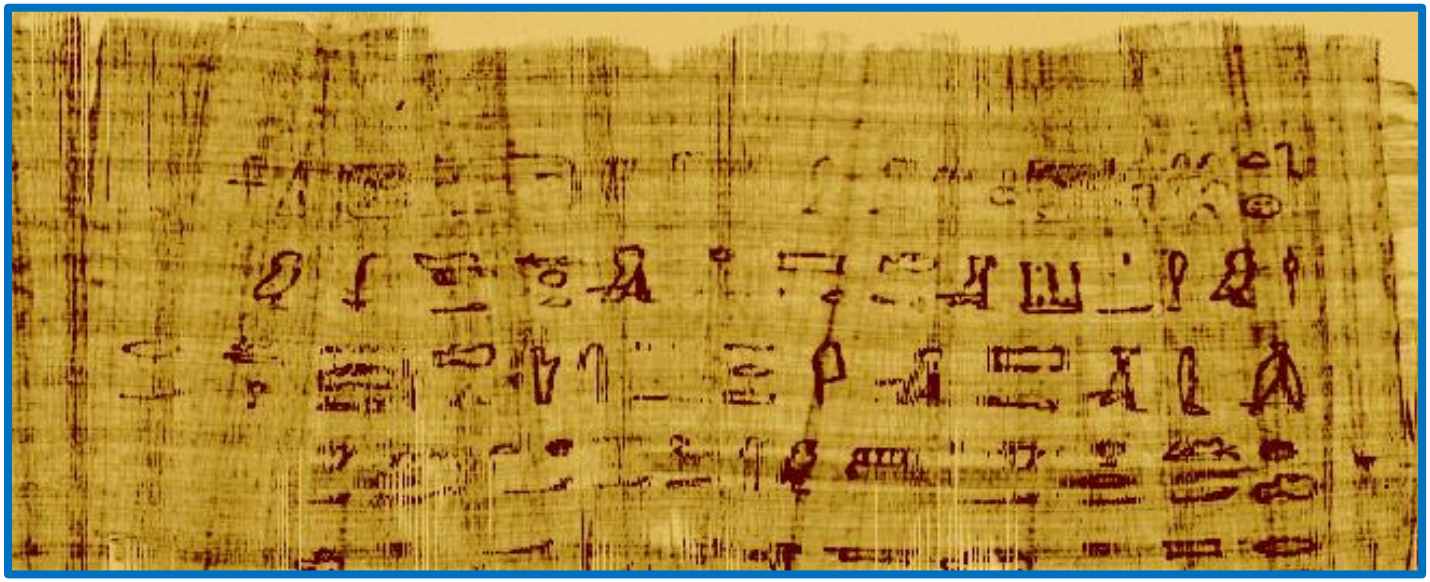
- The result of step 2 on slice 122 is the following:

- Finally the reconstruction step is performed.

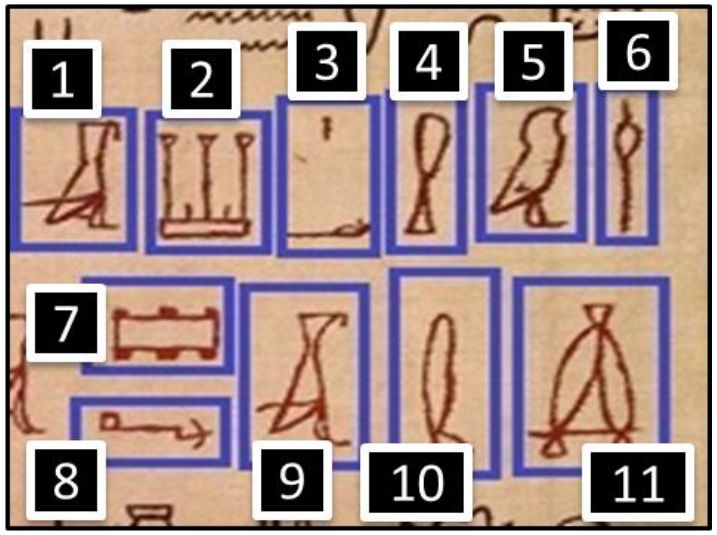
Result

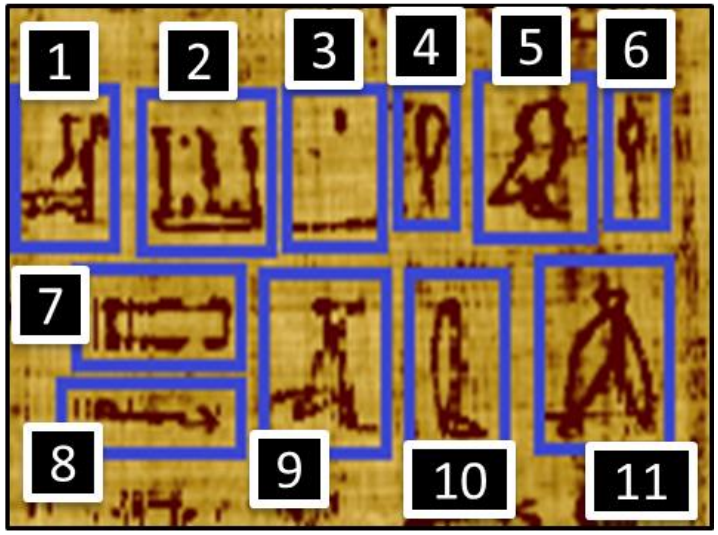


Result in false colors



Comparison





The highlighted symbol are clearly recognizable

Conclusions

- In this paper, we propose a method for virtual unrolling of papyri.
- This work is motivated by the criticality of a physical papyri unrolling, because of the high risk to damage the cultural heritage.
- The experimental results show that this approach is valid, since many symbols of the original papyrus become visible after the virtual unrolling.
- In the future works we consider to solve the overlapping sheets issue for each slice, so to use more than a single path. In this way a better and more accurate result could be obtained.

Thanks