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X-ray computed tomography applied to investigate ancient manuscripts

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Summary. — I will describe in this paper the first results of a series of X-ray tomography applications, with different system setups, running on some ancient manuscripts containing iron-gall ink. The purpose is to verify the optimum measurement conditions with a laboratory instrumentation —that is also in fact portable— in order to recognize the text from the inside of the documents, without opening them. This becomes possible by exploiting the X-rays absorption contrast of iron-based ink and the three-dimensional reconstruction potential provided by computed tomography that overcomes problems that appear in simple radiograph practice. This work is part of a larger project of EPFL (Ecole Polytechnique Fédérale de Lausanne, Switzerland), the "Venice Time Machine" project (EPEL, Digital Heritage Venice, `http://dhvenice.eu/`, 2015) aimed at digitizing, transcribing and sharing in an open database all the information of the State Archives of Venice, exploiting traditional digitization technologies and innovative methods of acquisition. In this first measurement campaign I investigated a manuscript of the seventeenth century made of a folded sheet; a couple of unopened ancient wills kept in the State Archives in Venice and a handwritten book of several hundred pages of notes of Physics of the nineteenth century.

1. – Introduction

I explored in the present work the opportunity to apply X-ray computed tomography in reading ancient manuscripts. The technique is particularly useful when the conservation conditions of the manuscripts is not allowing their unfolding or for those that are still closed and sealed. Radiograph demonstrated that X-rays absorption is effective if there is enough contrast between writings and paper. This is possible thanks to the

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Fig. 1. – Views of the State Historical Archives of Venice. Photoreproduction performed by "Sezione di fotoriproduzione dell'Archivio di Stato di Venezia", published by act No. 68/2017.

widespread use, from many centuries and all around Europe, of iron based inks, the Iron Gall inks [1, 2]. Several chemical investigations proven the use of this type of inks also for administrative documents [3-5]. However, single radiograph can seldom be enough to read the complete text as in most cases pages of the manuscript are folded a number of times or we have more than one page in a single document. In such a case, simple radiograph causes superposition of writings in the output image. Computed tomography allows the reconstruction of the whole document and potentially the virtual separation of single pages of the manuscript. Moreover, by scanning the document at many angles, it improves the contrast between paper and ink even when it is poor due to low iron concentration. I obtained encouraging results on both benchmark and historic manuscripts by adjusting optimal scanning geometry and parameters with an experimental high-resolution CT equipment developed at the Department of Physics and Astronomy in Bologna. The CT system is in fact also portable, but I will describe more in detail the system's features later. I have to point out here that I carried out this experimental work in collaboration with researchers from EPFL as in the framework of the more extended project "Venice Time Machine" [6] there was an interest in evaluating different scanning and digitizing techniques on ancient documents. The project focuses mainly on the Venice State Archives, a large library with thousand documents —more than 80 km (fig. 1). The Archives contains all the administrative Venetian documents, from work contracts to tax declarations, from ship records to notary papers, documenting the every aspect of 10 centuries of the Venetian Mediterranean Empire. Thousands of Venetian last wills, even famous ones, form a consistent part of this collection.

For most of the documents and books kept in the Archives, it is possible to use a standard scanning device that operates with a special photographic set-up, in visible light (fig. 2). However, some of the documents remained closed with their original seal until now - like the majority of the last wills. Thus, their content is still unknown as is not recommended to open them because of their conservation conditions (fragile) or to preserve their status of original untouched document (conservators decision). In this case, the reading technique with X-ray tomography is really an interesting option and, probably, the only one available.

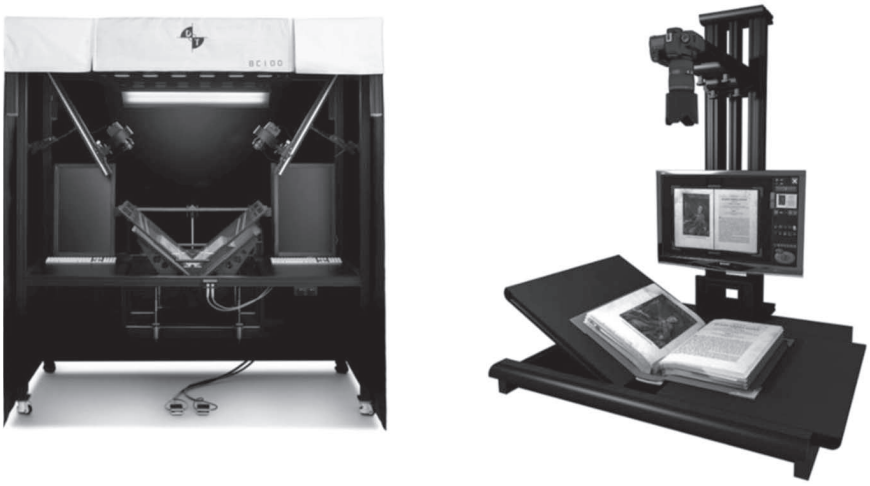

Fig. 2. – A couple of digital acquisition devices designed for documents. These work with visible radiation and are suitable just for documents one can safely open.

2. – Materials and methods

I carried out a first investigation on a manuscript with the experimental CT system of the Department of Physics and Astronomy in Bologna (fig. 3). The system is composed of three main components. The first is the X-ray radiation source: a 130 kV maximum voltage, low power microfocus X-ray tube (Kevex PXS10-65W) with a focal spot as small as 6 microns at minimum power. The second is a high dynamic range 25 cm × 20 cm area

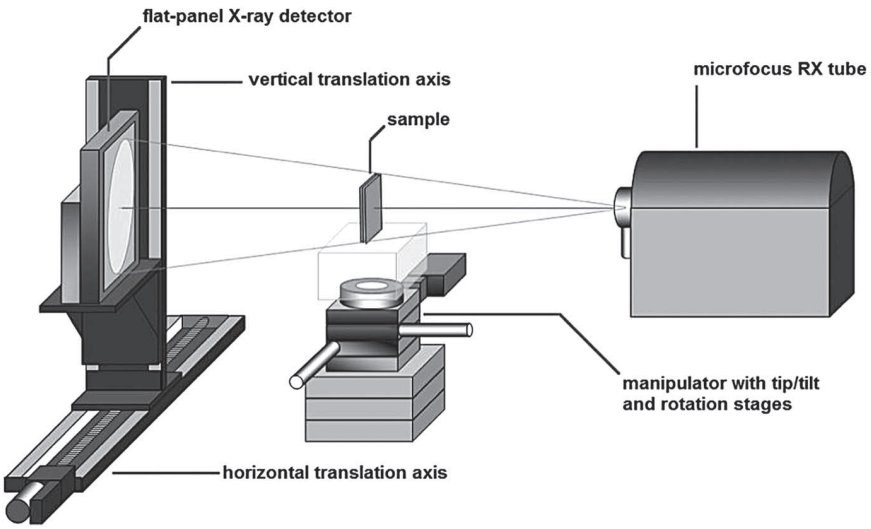

Fig. 3. – Scheme of the X-ray tomography set-up that I used for all the CT acquisitions of the present work.

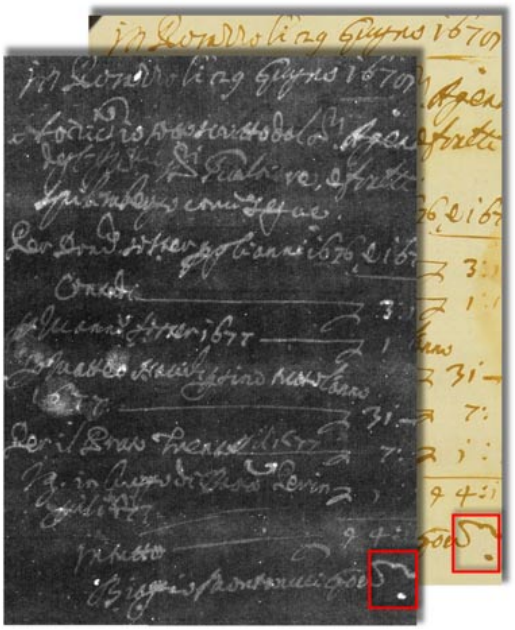

Fig. 4. – Single-sheet manuscript dated 1679 used as a benchmark for first CT tests. Left: visible photograph. Right: radiograph. The square on the left image indicates the area of the X-ray Fluorescence measurement (data extracted from [7]).

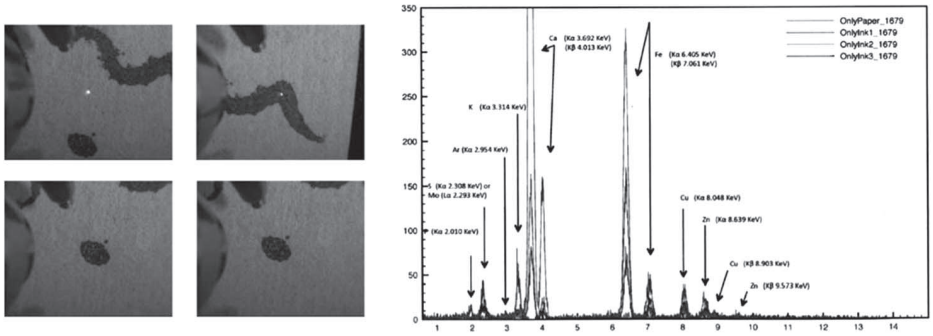

Fig. 5. – Here I report points and results of the X-ray Fluorescence measurements, where a high response by iron present in the ink is clearly visible.

X-ray flat-panel digital detector (VARIAN PS2520D) with a pixel size of 127 microns. The third is a precision rotation stage (Physic Instrumente M-038) with double tip/tilt stages for precision alignment. The manuscript is quite old but not that precious, thus, it was used as a benchmark. It was supposed to have a high concentration of iron in the ink. This first document, in fact a manuscript dated (1679) containing accounts of some kind of goods, was previously investigated by researchers at EPFL by means of both X-ray radiograph and X-ray fluorescence to see the contrast with a typical digital detector related with a more quantitative iron content measurement [5, 7] (fig. 4, fig. 5). Later on, I performed a CT scan on it.

TABLE I. – *Scanning parameters of the first CT test on the folded manuscript (left) and for the book of physics (right).*

Scanning Parameters - 1679		Scanning Parameters - Book	
Voltage	40 KV	Voltage	70 KV
Current	85 μA	Current	55 μA
Filtration	NO	Filtration	NO
Frame Rate	1 fps	Frame Rate	2 fps
Frame Average	1	Frame Average	16
Projections	900	Projections	900
Angle Range	360 deg	Angle Range	360 deg
Pixel Size (Detector)	127 μm	Pixel Size (Detector)	127 μm
Source-Detector dist.	364	Source-Detector dist.	364
Source-Object dist.	182	Source-Object dist.	182
Object-Detector dist.	182	Object-Detector dist.	182
Magnification	2	Magnification	2
Voxel Size (Object)	64 μm	Voxel Size (Object)	64 μm

Table I shows the scanning parameters I used for the first successful test. I used low voltage to have more contrast on this paper and the thin layer of ink. The scanning time was of the order of one hour. In order to simulate other types of documents with more than one page I folded the single-sheet manuscript a number of times. Results were encouraging. Slicing the reconstructed volume generated from computed tomography data it was possible to see and almost completely separate different parts of the text (fig. 6).

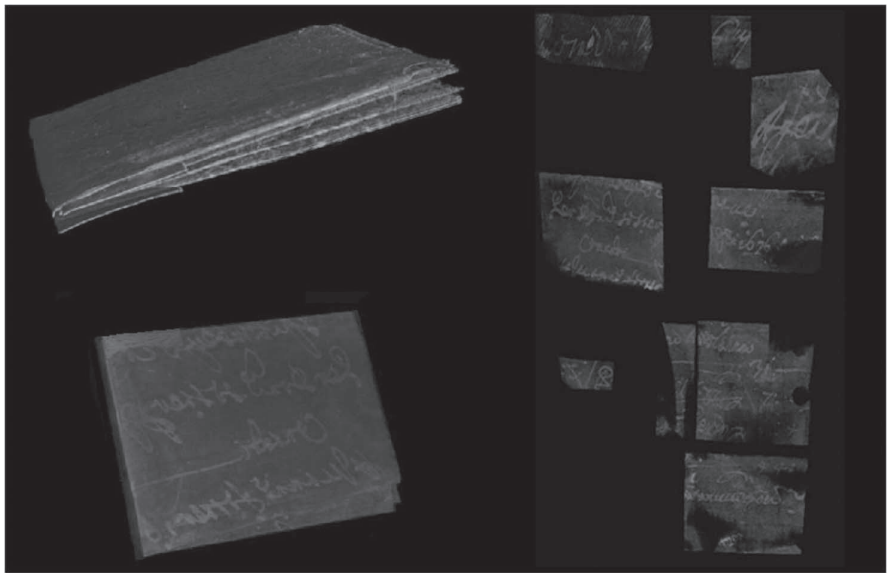

Fig. 6. – Results of the CT scanning of the first folded manuscript where writings are clearly visible. On the right part of the page put together after slicing the reconstructed volume of the document.

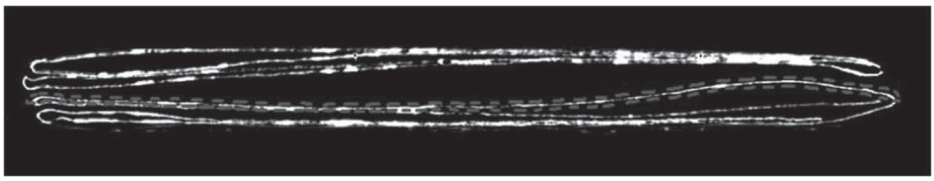

Fig. 7. – Problems in separating pages after CT reconstruction is a main issue if one aims to read out all the text of the document. It is possible to solve this problem by means of further advanced processing of reconstructed data.

However, it was not possible to reconstruct and read the entire document, as some pages were so close that separation was very difficult (fig. 7). This is a problem of both spatial resolution of the CT system as well as of segmentation of the reconstructed data. Even if resolution is enough, one needs, in any case, a segmentation procedure that can follow the shape of the pages. In most cases this shape is not flat, thus accurate segmentation of orthogonal sections will be required in order to put in evidence the writings on one single page.

After the first encouraging experience, researchers at EPFL selected a number of closed wills from the Venice State Archives too and transported in the labs at DIFA for CT investigation with the same set-up we used for the benchmark. Here I report results obtained for two of them, the last will of Giuseppina Alchier (1634) and Dona Cataruccia (1351) (fig. 8). Both envelopes are closed. On the outside of the envelopes it is possible to see some writings that at XRF analysis show a good content of iron thus

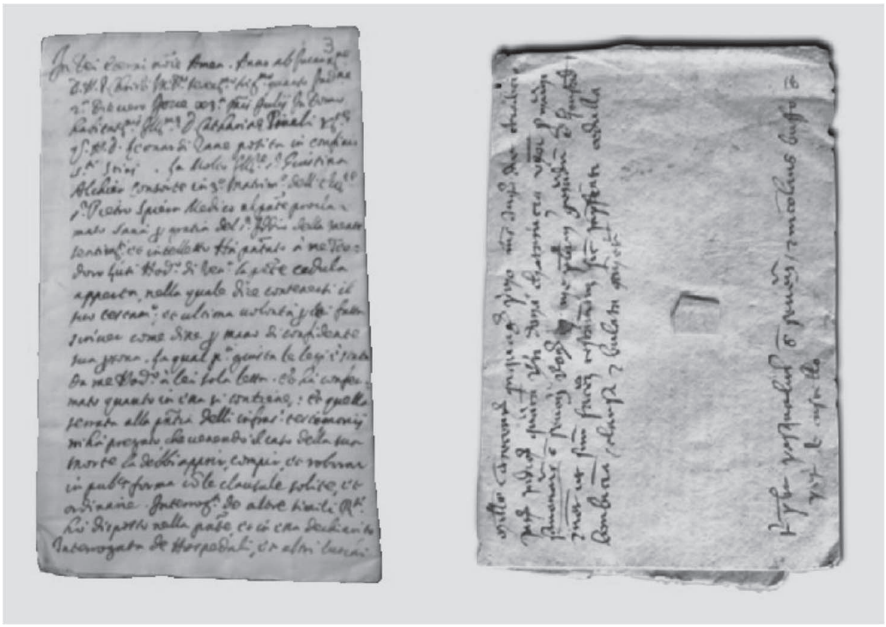

Fig. 8. – Last wills of two women, Giuseppina Alchier (left) dated 1634 and Dona Cataruccia (right) dated 1351. Both documents are closed. Photoreproduction performed by "Sezione di fotoriproduzione dell'Archivio di Stato di Venezia", published by act No. 68/2017.

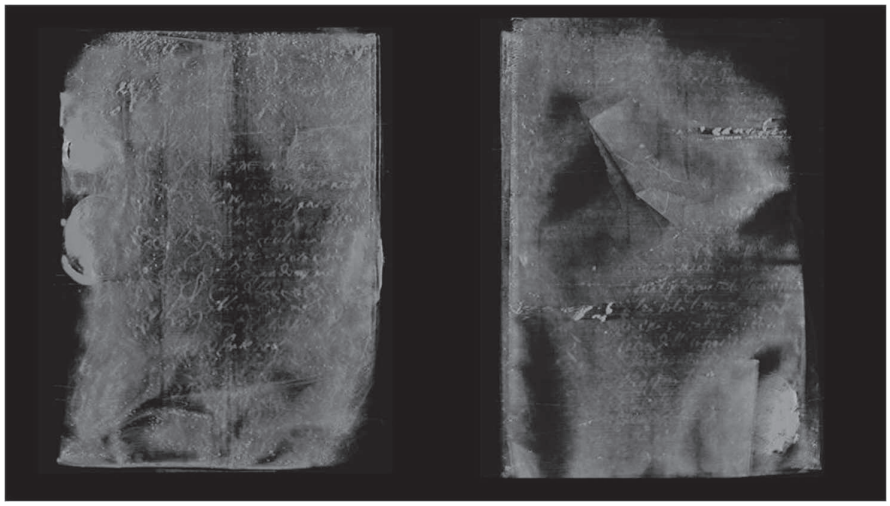

Fig. 9. – A couple of pages inside the wills of Giuseppina Alchier show writings quite clearly readable. A small hidden paper also appeared inside the document.

letting researchers suppose the use of iron based ink for the writings inside too. The CT analysis confirmed this hypothesis.

It was possible to see writings in many pages inside the documents and thus historians have a chance to have a glimpse of the last will of the two women (fig. 9 and fig. 10). However, not only the CT inspection and further segmentation of the pages, but also the ancient language is challenging for experts of the Venice State Archive. A parallel multidisciplinary work is still required to read out correctly the content of the documents.

A last investigation of this first session consisted in scanning a whole book in order to assess the capability of our system to put in evidence writings with a significant thickness of paper and not only few pages as in previous cases. Thus, I managed to scan

Fig. 10. – Virtual unfolding of Dona Catarucia's last will (left) and an example of one page as it appears after post processing of the CT (right). Writings are clearly visible.

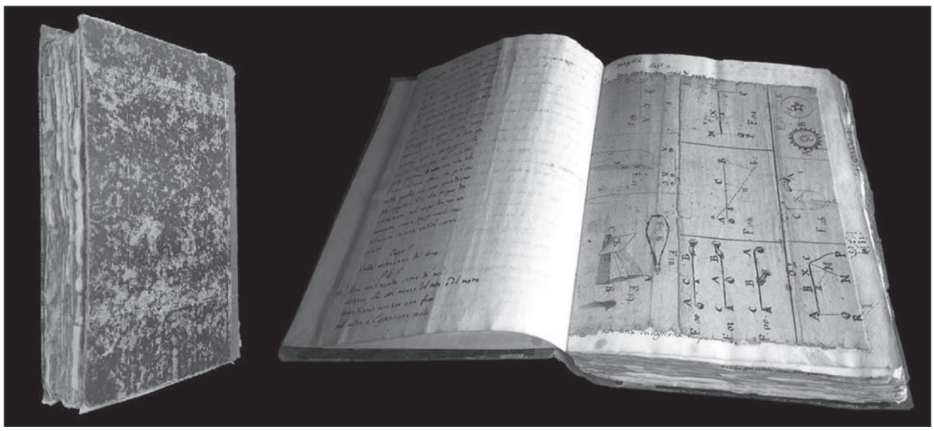

Fig. 11. – An old book of physics.

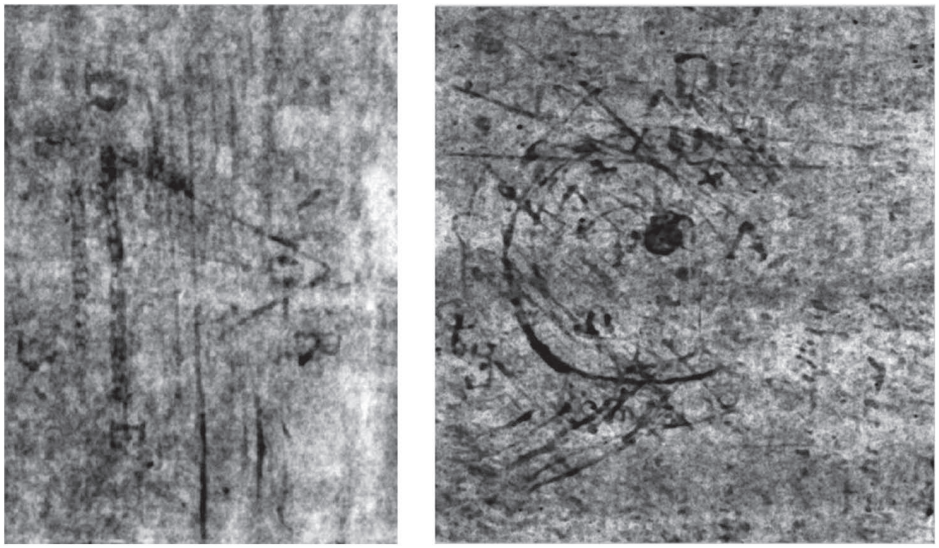

Fig. 12. – Some writings and drawings inside the pages of the book emerge through CT slices.

a century old book of physics (fig. 11). I reported the scanning parameters for this object in table I shown above. A significant increase in tube voltage was necessary in order to have a good signal. This might affect the contrast between iron based ink and paper. However, after the reconstruction of the scanned portion of the book, it was possible to spot different writings and drawings on pages inside the book, which was a good result (fig. 12). This shows how in principle our tomographic system has enough resolution and contrast to read also a book written with the typical iron-based ink used in old times. After this experience, I can affirm this method is not only suitable for closed or damaged documents, but for books too, when they are in bad conservation conditions and one prefers not to open pages or handle the object too much.

3. – Conclusions

I can affirm, as a conclusion of this work, that the attempt to read out ancient documents written with iron-based ink was in the end successful. I could confirm the hypothesis of researchers at EPFL that documents in the past centuries were written using a quite iron-rich ink, also found by means of X-ray Fluorescence. I could fully confirm this statement by means of high resolution X-ray computed tomography analysis. Moreover, I found that the CT equipment at the Department of Physics and Astronomy in Bologna has enough contrast and resolution to read writings through CT slices. This was true not only for the first benchmark paper I scanned but also for enclosed wills coming from the Venice State Archive, which constitute the real historical significant result of this work, as well as for and old book of several pages that was really more challenging. The method is therefore promising and effectively suitable. One issue is that a specific software capable to separate efficiently different pages in the reconstructed volume is not yet available. A large amount of operator work is still required to find out writings and put them together. The development of segmentation methods together with increased spatial resolution CT set-up will probably help in overcoming this limitation. We are working to develop an effective segmentation method on data coming from real case measurements done in this work. Finally, we conclude that, with results obtained in this work we can state this method is useful in practice and, especially in case of valuable documents that are in bad conservation conditions, it is probably the only way to attempt reading their content effectively.

* * *

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