Multidisciplinary study of the Shroud of Arquata, “extractum ab originali”

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1. The Shroud of Arquata, a touch of history
2. Analyses of the cloth and stains
3. UV induced fluorescence
4. Imaging Topological Radar Scanner
5. Laser Induced Fluorescence
6. UV-visible-near infrared absolute reflectance
7. Summary of the results
Arquata del Tronto
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The Shroud of Arquata, a touch of history

- **1655:** Parchment signed by the Bishop of Alba, stating that during the TS exposition in Turin on the **4th May 1653**, a copy of the TS **20 hands long and 5 hands wide** was put in contact with the TS, and that the copy was then given back to Ft. Massimo Bucciarelli, from Arquata. M. Bucciarelli was the brother of the Bishop Giovanni Bucciarelli, formerly secretary of the Bishop Federico Borromeo, nephew of S. Carlo Borromeo, who had an important role in moving the Shroud from Chambery to Turin in 1578.

- **1656:** The Bishop Bucciarelli dies and leaves the copy of the Shroud to the Franciscan Friars of Arquata who preserved it in the convent of St. Francis, Borgo di Arquata.
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The AS was moved in a convenient position inside the S. Francis church. The cover glass was removed, but we were not authorized to unstitch the AS from the underlying red silk.
Analyses of the cloth and stains

Our Arquata Shroud Photo, white-balanced.
The AS is about 5 m long, but it is folded to have the same length of the TS

Recent Turin Shroud Photo (Courtesy David Rolfe)
Analyses of the cloth and stains

Drawing or paint are not evident in the fuzzy face of the Arquata Shroud. The complete lack of anatomic details makes it very different from the other copies.

From Barta, Carrascosa: SRE 7, 2526 (2012)

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AS linen is a plane weave, warp (26/cm) weft (27/cm). Av. thickness 0.27 mm, FF 83%, weight $\approx 1.97$ Kg

HR photographs show that

- Warp threads diameter are thinner inside than outside the human figure, in average.
- The red silk underlying the AS may contribute to the perception of the figures.
Analyses of the cloth and stains

AS photo, white-balanced

Red component of the photo

Blue component of the photo

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To eliminate the underlying red silk contribution thus enhancing visibility of reddish signs, we disassemble the photo in RGB components and subtract B-R. Painted thin scourges and details of heel and hallux appear only in the B-R image.
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Pigments absorb UV more than cellulose. Then, pigment traces are darker and then more visible when illuminated by UV radiation. Note a lips-like segment and the “reversed 3” on forehead clearly visible in the fluorescent photo, as well as two drops of stucco/plaster. Nose and eyes are not visible.
Comparison positive vs. negative
Comparison positive vs. B-R

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RGB-ITR is the acronym for Red Green Blue Imaging Topological Radar

It’s based on double Amplitude Modulation Technique (190MHz/5MHz)

Collects five information per pixel – three colors and two distances

Working range of 3-30 m

Modular configuration – suitable for hostile environments

Works with three independent laser sources – 660 nm, 532 nm, 440 nm

Scanning mirror movement:
- Horizontal movement:
  - Scanning range: 80°
  - Step precision: 0.002°
  - Motor speed: 20°/s
  - Max pixels per row: 40k pixels
  - Max time per row: 4s

Scanning mirror movement:
- Vertical movement:
  - Scanning range: 310°
  - Step precision: 0.002°
  - Motor speed: 20°/s
  - Max pixels per row: 155k pixels
  - Max time per row: 15.5s

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Shroud 3D model

View of the 3D image

A detail of the 3D image

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Added materials absorb more IR radiation than cellulose. In the IR image, letters and silhouette and false holes appear darker than background. The longer than visible $\lambda = 800$-nm gives information less superficial than the visible image, at least $2\lambda$ deep.

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**LIF (Laser Induced Fluorescence)**

Fluorescence mechanism:

• An UV photon is absorbed by the molecule.
• The molecule jumps from the fundamental to the excited level.
• After a certain decay time (ns – μs) it relaxes to an intermediate level by a non-radiative transition.
• The molecule emits light in the visible range (fluorescence emission), decaying back to the fundamental level.

Decay time and fluorescence emission are characteristic of the molecule

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The system scans the selected area line by line and provides fluorescence spectra for single pixels of each line.

- **L**: Nd:YAG at 266 nm; **M**: mirrors;
- **C**: cylindrical lens; **O**: Collecting objective
- **S**: Spectrometer; **D**: ICCD

**Portable hyperspectral system**
- COMPACT
- REMOTE (up to 20 m distance)
- FAST

It scans large surfaces remotely

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Preliminary LIF results

LIF at 405 nm captured at 6m distance. Spatial resolution 0.5cm

LIF false color image. 
R=380 nm 
G=440 nm 
B=485 nm

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Preliminary LIF results

Spectral differences among different areas

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Preliminary LIF results

Spectral differences among different areas

Typical cellulose fluorescence spectrum inside and outside the figure (peaks at 380, 440 and 480 nm)

Lateral areas of Arquata Shroud
Renaissance papier-mâché

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Spectral differences among central stains

LIF spectra of typical Renaissance reddish pigments

- Terra rossa
- Lacca di Robbia
- Red ochre
- Rosso di Pozzuoli
- Rosso inglese
- Rosso di Ercolano
- Cinnabar HgS

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Reflectance spectra were measured with white ($R_w$) and then black ($R_b$) backings. From these values the original Kubelka-Munk (KM) theory allows to calculate the reflectance $R_\infty$ that would have an infinite layer of the same sample:

$$R_\infty = f(R_w, R_b)$$
$R_{\infty}$ spectra can be transformed to absorption coefficient spectra $\alpha(\lambda)$ of the cellulose fibers by using a new extension of the KM theory [1].

Absolute absorption spectra show at least 2 different behaviors:

1) One group of spectra is similar to those observed in samples with oxidized cellulose fibers, for instance in artificially or naturally aged papers.

2) Another group (letters and blood-like stains) is most likely due to pigments /dyes which show specific spectral features in the visible wavelength range.
As a preliminary result, we found methemoglobin absorption spectra is compatible with the sharp change of derivative at 550 nm observed in the absolute absorption spectrum of stains simulating blood. It is possible they are made by dye+MetHb.
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We have illustrated **preliminary results** of the huge amount of data collected by several **non-invasive** optical techniques in the **first in-depth analyses of the Shroud of Arquata** (18-20 June 2014). Our results show that **it does not exist a single equipment** able to identify the methodology used to make the image and the stains on the cloth. It is only the **merging between the results of different methods and tools** which may give reliable answers to our scientific questions.

**HR photos disassembled in RGB components** allow to: a) **point out faint and subtle pigments simulating scourges** on legs; b) identify the faint contours of anatomical details like feet; c) **point out invisible traces inside the figure**, possibly due to rubbed threads or streamers/drained water.

**FFT** filtering gives cleaner images, but the improvement is limited by the very irregular weave and threads diameters having a broad spectrum of spatial distribution.

**UV-induced fluorescence** points out **pigments used to simulate blood marks on heads**, and **extraneous materials** perchance added, like e.g., plaster drops.

**RGB ITR** makes a HR **3-D colorimetric map of the whole Shroud**, creating a database for future analyses, in order to monitor the effective conservation of the cloth and visibility of stains, time after time. It may be also used for high-impact didactic and museum exhibitions.

**IR ITR** image shows that the **silhouette of the human figures, the false holes and the letters are drawn with materials penetrating** into the linen threads.
Summary and remarks

✓ **LIF** a) shows the *same cellulose-like fluorescence inside and outside the figure*; b) points out a narrow fluorescence peak at 475 nm of the *letters* and of one stain, suggesting they are made by a different pigment wrt the figure contours, blood, etc. c) Fluorescence spectrum of stains simulating blood *does not match any of the seven reddish dyes* commonly used during XVII century. The most similar spectrum, albeit different, is that of *Lacca di Robbia*.

✓ **Raman** spectra of cellulose and stains are overwhelmed by the huge fluorescence signal triggered by the IR laser, which hides the lower-intensity Raman fingerprints of cellulose and other materials.

✓ **Absolute reflectance spectra** a) confirm the LIF results showing the same oxidized cellulose both inside and outside the figures; b) *dyes are present in the letters* and in stains simulating blood; c) *blood stains spectrum shows a pigment possibly mixed* with substances having a drop of absorption at 550 nm, thus explaining why LIF spectra do not match those of reddish dyes; d) the image on the AS was made overall by a degradation process of the linen able to speed up oxidation of the cellulose fibers.

✓ When pointing out *advantages and limits* of each technology considered, our results may give a contribution to *identify some of the most appropriate tools and experimental cues* for a successful in-depth analysis on the Shroud of Turin.
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Thank you for your attention!
Questions are welcome
References

- For a survey of the ENEA technologies available for the diagnostics and preservation of Cultural Heritage, see the special issue of EAI: *Knowledge, Diagnostics and Preservation of Cultural Heritage* edited by P. Clemente, P. Di Lazzaro, R. Giorgi (ENEA, 2012).