International Journal of Archaeology
2025, Vol. 13, No. 1, pp. 63-68
https://doi.org/10.11648/j.ija.20251301.16

SciencePG
Science Publishing Group

Research Article

Photoelectric UV Fluorescence Investigation of the Turin Shroud Revisited

Samuel Pellicori*

Pellicori Optical Consulting, Santa Barbara, CA, USA

Abstract

Photoelectric spectroscopic fluorimetry (PEF) was a set of analytical data collected during the 1978 scientific investigation of the Turin Shroud (TS). Simultaneously with PEF, UV-induced fluorescence photography and visual microscopy were recorded. This study uses data from the three optical disciplines to interpret the PE measurements with the objective of identifying those features on the TS that emit fluorescence when stimulated by UV. Fluorescence as recorded by PEF has been interpreted as emitted by the body image. That conclusion contradicts visual observation and UV florescence photographic imagery. The PEF-reported body fluorescence is found to be the result of the higher signal contributed to the total by fluorescing background cloth included in the measurement areas. A secondary objective of the study was to provide input relevant for exploring the chemical-physical properties and their differences of the body image, faintly scorched, and blood areas. Application of non-destructive updated spectroscopic, fluorometric and imagery analytical technology can benefit forensic, conservative, and preservation investigations of objects of historical value.

Keywords

Fluorescence Imaging, Turin Shroud, Ultraviolet, Optical Analytical Techniques, Preservation Monitoring

1. Introduction

The Turin Shroud is believed to be one of the most extensively studied of historic relics. In 1978, a multidiscipline scientific team employing non-destructive processes and equipment collected optical and other physical data related to potential causes of the image [1]. Visually and photographically, the body image and other features present ~~a~~ low contrast against the aged linen cloth background that appears to be decreasing with time. Extra-visual and other quantitative analytical tools were employed during the 1978 investigation to enhance the optical density and spectral properties of the various features and collect data that is potentially relevant to feature origin and preservation. This study proposes the processing of spectral data to aid in distinguishing the fluorescent properties of different features and materials.

UV-induced fluorescent (UVIF) emission is a *surface-specific* non-destructive analytical remote optical technique that uses UV radiation of wavelengths shorter than ~400 nm to stimulate longer-wavelength electronic transition emission. (UVIF is not to be confused with the Raman scattered fluorescence that is stimulated by deeper-penetrating IR lasers, and therefore appropriate for bulk materials analyses). UVIF probes millimeter-to-centimeter surface areas to nanometer and micrometer depths and is applicable to forgery detection and to conservation of historical objects because it

*Corresponding author: pellopt@cox.net (Samuel Pellicori)

Received: 4 April 2025; **Accepted:** 16 April 2025; **Published:** 22 May 2025

can assist in the analysis of surface contamination and in the identification of chemical reagents and reactions associated with bio-chemical materials. It is used in forensic analysis of chemical dyes and pigments and unknown stains and in quantifying and monitoring environmental influences related to conservation and preservation.

Challenges to the ability to isolate and identify features of interest and origins are created by the presence of visible stripes (banding) differences within the weave of the Turin Shroud. These are clearly evident in UVIF images. The probable causes are non-uniform processing of the linen warp and weft flax threads or their different sources, coupled with the ubiquitous distribution of adventitious debris, and water stains, etc. When stimulated by short-wave UV, many organic and inorganic chemical materials selectively emit or absorb spectrally specific signatures characteristic of their composition and state of preservation, thus enabling the isolation and characterization of features by spectroscopic analysis and monitoring.

Material emission signatures at wavelengths 400 to 700 nm as stimulated by 365 nm UV were recorded by photoelectric spectrophotometry and by film-based photography during the 1978 scientific investigation [2, 3]. That data combined with microphotography, is analyzed here from a complementary perspective and confirms or reveals new information about some features of the Turin Shroud.

2. Equipment and Data Collection During the 1978 Investigation

Photoelectric spectral fluorescence measurements were collected in selected feature areas of the TS using a 0.25 m dual grating monochromator arrangement [2]. The source monochromator illuminated, at 45° incidence, a 6 mm x 3 mm area containing the equivalent of ~244 thread surface widths (considering thread widths ~0.27 mm in the 3:1 herringbone trill weave pattern). The separate stimulation and detection monochromator subsystems produced a high degree of isolation of the stimulation- and emission- energy wavelengths and high stray light rejection. The illuminating monochromator was set to the 365 nm mercury vapor emission line of a 200 W mercury arc lamp and the detection monochromator was scanned over the visible-range to collect fluorescent emission data. A long-wave pass visible-blocking filter further reduced any possibility of stray light contamination and ensured the sensing of only long-wave fluorescing energy. The receiving monochromator scanned the spectral range 390 nm to 700 nm with 8 nm spectral resolution. A thermopile for absolute calibration and a MgO white diffuse reference surface were used to establish the photometric signal scale and instrument's spectral signature [2].

Film-based UV-stimulated visible-wavelength photographic images were taken using Kodacolor 400 color negative film and a Hassleblad EL camera with 2-1/4-inch format [3]. UV stimulating energy was isolated in a 40 nm-wide UV excitation passband centered at 355 nm that was defined by two identical 15-cm diameter specially constructed filters. The UV filters were mounted on two 200 watt-second xenon strobe lamps and directed at opposite 45^0 illumination incidence. The illumination plane was oriented in the long (4 m) dimension of the TS. At wavelengths outside the passband, transmission of these filters decreased to < 0.1% at 435 nm and averaged < 0.01% to ~700 nm. The camera was filtered with a Hoya L-42 UV-absorbing glass filter that transmitted visible light and removed all energy at wavelengths shorter than 400 nm [3].

The color negative film required lab processing to remove the obscuring orange color of the base and color-sensitive layers to convert them to color positive transparencies. Miller reproduced the original color negatives as 4 x 5 in. color positives and provided the author with a set of 35 mm transparencies made from the original color negatives. These were processed digitally and the corrected UVIF photography [4]. Colorimetric and fluorometric properties were recently related to photoelectric spectrophotometry [5, 6].

Photomicrographs were made of the same areas as measured with PE but with higher spatial resolution to visualize the feature and its distribution within the weave structure [7]. Forty-five-degree incidence employed in reflectometry, fluorimetry and microphotography illuminated not only the tops of the weave containing the feature being investigated, but also larger thread side areas.

3. Photoelectric UV-stimulated Fluorescence Data Collection

Gilbert and Gilbert published photoelectrically measured fluorescence curves of TS features including body, scorch and blood areas as well as clear areas [2]. Their curves show apparent fluorescence emission from all areas. UVIF photos and visual reports, in contradiction, reveal that the background linen in feature-less areas emits a greenish-blue fluorescence and that the overlying body image and other features appear to be absorbing and non-fluorescing. In UVIF photography, body features do not exhibit fluorescence. Except for faint scorches that emit reddish fluorescence, other features on the TS do not fluoresce [3]. Heat-induced chemical reaction products are believed to be the responsible fluorescing species in faint scorches [1, 3].

We tested the hypothesis that brighter underlying cloth fluorescence is the dominate contributor to the total measured fluorescence of the apparently fluorescing body and other features. G & G photoelectric data plots were enlarged and manually digitized to test this hypothesis; Figure 18 of reference 2. maps the sampled locations. All PE measurements were made at the same radiometric sensitivity scale and expressed as arbitrary units because they are not absolutely calibrated emittances.

Figure 1 shows the fluorescence emitted by clear background areas that are physically close to the body features, tip of the nose and heel, which are plotted in Figure 2. Clear areas F4 and F3B are near the figure's right arm area B1F is located at the dorsal end of the cloth. The assumption is made that the emission from the background areas F4 and F3B represent the inherent background emission over the entire cloth area.

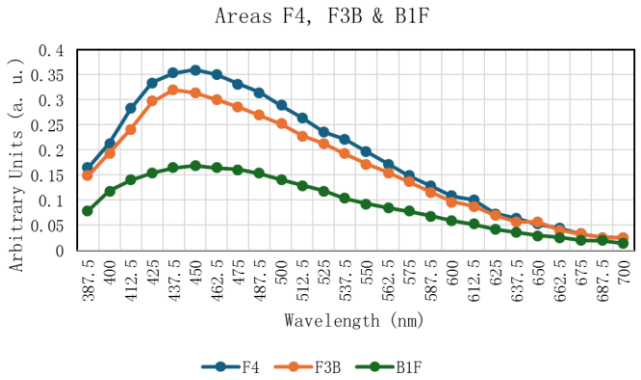

Figure 1. *Photo-electrically-measured fluorescence of featureless areas F3B and F4 that are physically close to the measured heel, nose, and blood features. Area B1F is suspected of being contaminated by a water stain.*

Figure 2 shows assumed "fluorescence" intensity measurements of the visually densest body features. Notice the general spectral similarity between the body features and the clear background cloth but at lower intensities than the background.

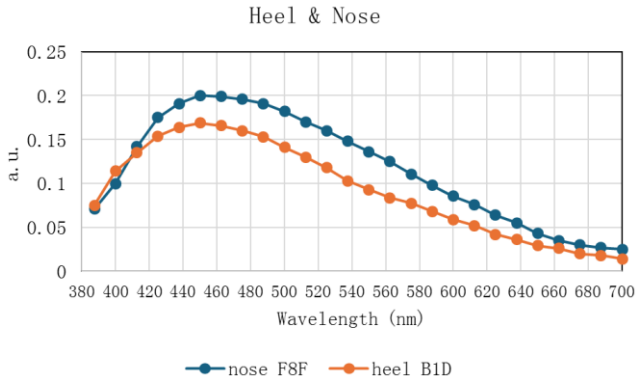

Figure 2. *Photo-electrically-measured fluorescence emitted from two dense body features. From Gilbert and Gilbert [2]. Points were manually read from G & G plots to a precision of 0.002 arbitrary units (a. u.).*

A lightly scorched area, B3E, is located between two burned areas; blood stains F3E (wrist) and F6B ("lance wound" with measured differences <0.01 units were averaged and plotted.

The clear area fluorescent emission signals (F4 in Figure 1) were subtracted from the total values of nose, calf, heel, blood and scorch features and the residual intensities are plotted in Figure 3. While the PE measurements were made at the same system radiometric sensitivity, the relative areas occupied by the stain feature and the clear areas have not been considered. Therefore, absolute absorptance values are not available.

What remains after subtraction of the clear background intensities are negative values ~~of~~ broadly absorbing in blue and green wavelengths with minima near 450 nm, which preserve the spectral behavior indicative of the absorption of the body, scorch and bloodstain features. Negative-trending features (such as blood) that contain image fiber areas with high self-absorption attenuate the fluorescent intensity of the underlying clear background emission more strongly. The residual in faint scorch area is positive in the long wavelengths indicting fluorescence emission above the background values. UVF images show this reddish hue emission, see in Figures 4 and 5 below [3]. Positive-trending values for the calf area suggest the background fluorescence is also a large component of that measured fluorescence signal. In blood wound and flow areas, fluorescence from serum might also contaminate the emission spectrum [8, 9]. Future higher spatial resolution would assist in better isolating and identifying fluorescing species.

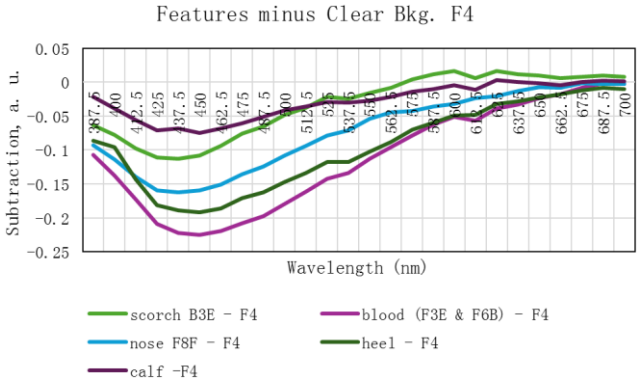

Figure 3. *Residual fluorescent intensities of nose, heel, scorch, and blood areas after removing (subtracting) the fluorescence contributed from a physically close-by clear background area. Positive values indicate emission above background cloth emission. Negative values indicate absorption or obscuration of the background emission by the feature noted. Faint scorches outlining the burned regions exhibit inherent reddish fluorescence (Figures 4 and 5 below).*

4. Photographic UV-stimulated Fluorescence Data Collection

Examination of UVF images from 1978 that contain the PE features assisted in isolating the features from underlying background. The Miller UVIF photos were digitally processed in Adobe Photoshop™ to enhance their contrast [4]. UV illumination was not uniform over the frame, but brighter in the central area. Analysis of the coordinates of the various

locations of features shows similar groupings as they are distributed along the non-uniform cloth areas and incident illumination [5, 6].

Figure 4 contains the nose, side blood and scorched areas that were measured.

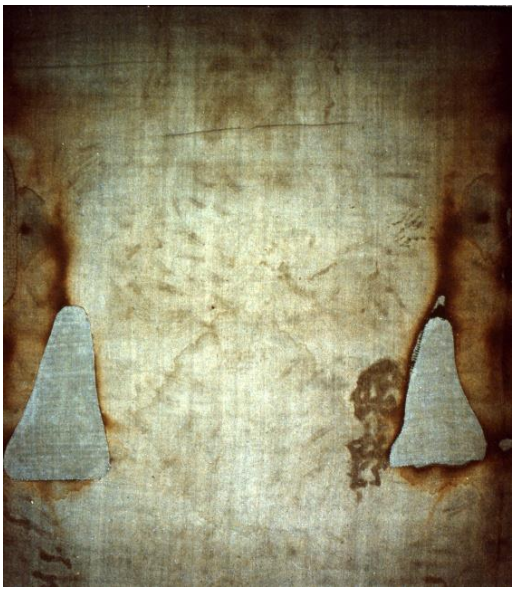

Figure 4. *UV fluorescence image of TS features including body (nose), side wound blood, and scorched areas. The lightly scorched areas bordering the burned areas emit a reddish fluorescence [3].*

Examination of the UVIF image of the foot region that contains the heel (BID), and "clear" area (BIF) reveals that these features might be contaminated by serum exuded by blood and by a water stain, respectively, therefore do not accurately represent pure body or clear background points. Serum has been shown to exhibit UVIF [8, 9].

Modified colorimetric coordinates of the PE fluorescence measurements show differences among features: body and clear background points are closely grouped while blood and scorch areas exhibit distinct groupings [LS]. The fluorescent differences correspond to reflectivity differences, as expected for optically dense features [2].

Figure 5. *UVF of feet showing the heel (B1D) that was considered a body image [3]. That area might be contaminated by serum. The "clear" area (BIF) to the lower left appears to contain a water outline.*

5. Coincident Microphotography

Photomicography of body areas shows body image density is present only on top fibrils of the weave, with large areas of the brighter underlying unstained cloth being exposed and thereby contributing to the total sampled area signal [7]. Local non-uniform geometrical illumination effects among the weave support the suggestion that the disproportionately larger brighter (more fluorescent) clear background areas, compared with feature areas, dominate the total measured fluorescence signals. Bright unstained linen thread areas underlying the image fibrils are evident in the visible light microscope images of the heel, nose, scorch, and blood-stained areas in Figure 6 [7].

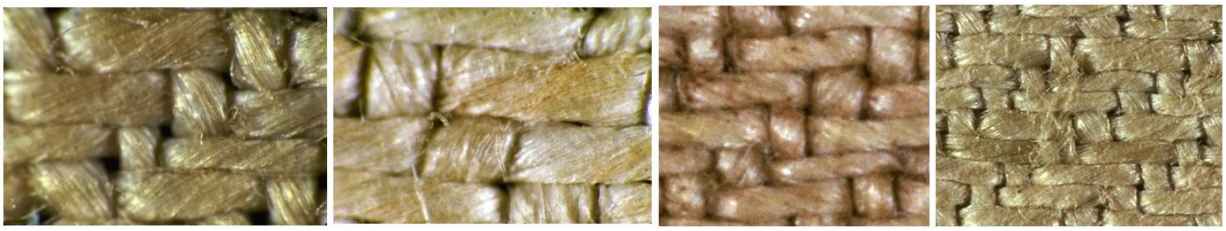

Figure 6. *Photomicrographs of the TS heel (left most), nose, blood, faint scorch areas (right most) [7]. Brighter underlying background areas of the unstained linen weave are evident.*

6. Discussion

The fact that the linen background fluoresces but the body image does not fluoresce suggests that differing reactions have operated to locally alter the cellulose properties and create advanced darkening of the superficial thread fibers seen in the body image. The degradation of cellulose results in darkening attended by the production of chromo- and fluorophores [10, 11]. Simulations based on heating linen in air at temperatures up to 175°C for varied times reduced spectral reflection. The addition of foreign materials to the linen accelerates the darkening and led to the suggestion that the body image appearance developed over time [12].

The body image process is hypothesized to involve conjugation and dehydration of cellulose [1]. The degradation chemistry of cellulose is well known: reactions can create double bonds that produce chromophores with characteristic spectral absorptances [10-12]. Cellulose degradation and attendant optical density increase appears to follow a continuum; from clear background areas to burned conditions [5]. From lab simulations, chemical reaction and the emission of fluorescence appear to be temperature dependent [13]. High-temperature reaction products, such as furfural, are associated with the borders of burned cellulose areas and emit reddish UVIF, as observed.

7. Summary and Conclusions

Revisiting the photoelectric (PE) fluorimetry collected during the 1978 scientific investigation of the Turin Shroud in conjunction with coincident UV-induced fluorescence and microscope imaging confirmed previously know or revealed new properties of the various features. Subtracting the fluorescent background contribution from the PE fluorescence measurements reveals differences in the fluorescence absorption behavior among various features. In agreement with visual and UVIF imaging it was confirmed that, among the body, scorch, blood features and cloth background, the only areas that exhibit fluorescence are featureless cloth areas and light scorches. The background clear emits a greenish-blue hue and faint scorches emit a reddish hue. PE measurements and hues recorded by UVIF photography agree.

The new results support the observations reported in subsequent publications including UV fluorescence photography that the body image does not itself fluoresce under UV stimulation. Significant background linen fluorescent emission is included in the sampled areas and in many cases dominates the integrated PE measurements, thereby confusing the true source of fluorescent light with specific features.

Photoelectric fluorimetry in conjunction with UV-stimulated fluorography has been demonstrated to be a useful tool in supplying corroboratory data related to the understanding of the origins of various features and stains present on historically important textiles and for monitoring their state of conservation. In the context of the TS and other culturally significant funerary and burial cloths, these tools can assist in the identification of the compositions of preparation materials and processes.

Since 1978, digital photography, LED UV sources and portable digitized spectro-fluorimeters have replaced film-based technologies in the study of ancient objects of historical or cultural significance. As a result, current and future investigations will provide permanent digitized records of data to be used in study and preservation efforts.

Abbreviations

PEF	Photoelectric Fluorimetry
TS	TS Turin Shroud
UV	Ultraviolet
UVIF	UV-induced Fluorescence
G & G	Gilbert & Gilbert
MgO	Magnesium Oxide
LED	light Emitting Diode Sources

Acknowledgments

Discussions with Dr. Kelly Kearse are appreciated. I thank the reviewer for comments and suggestions.

Author Contributions

Samuel Pellicori is the sole author. The author read and approved the final manuscript.

Funding

Pellicori Optical Consulting.

Data Availability Statement

The data used in this study were read from plots in Ref. 2.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Jumper, Eric J., Alan D. Adler, John P. Jackson, Samuel F. Pellicori, John H. Heller, James R. Druzik, "A Comprehensive Examination of the Various Stains and Images on the Shroud of Turin", ACS Advances in Chemistry No. 205. Archaeological Chem. III, American Chemical Society 22, 447-476 (1984).

[2] Roger Gilbert, Jr., and Marion M. Gilbert, "Ultraviolet-visible reflectance and fluorescence spectra of the Shroud of Turin", APPLIED OPTICS Vol. 19, No. 12 I 15 June 1980.

[3] Miller, V. D. and Pellicori, S. F.: "Ultraviolet Fluorescence Photography of the Shroud of Turin", J. Biological Photographers Assoc. 49, No. 3, 71 (1981).

[4] Samuel Pellicori, "UV Fluorescence Imagery of the Turin Shroud – Digitally Revisited", Vol. 8, No. 2, 2020, pp. 32-36. https://doi.org/10.11648/j.ija.20200802.13

[5] Larry Schwalbe and Samuel Pellicori, "Analysis of Photoelectric Colorimetry and Fluorimetry of the Turin Shroud", International Journal of Archaeology. Vol. 11, No. 1, 2023, pp. 1-8. https://doi.org/10.11648/j.ija.20231101.11

[6] Thomas McAvoy, "Information in the Shroud of Turin About Its Variable Molecular Properties", International Journal of Archaeology. Vol. 12, No. 2, 2024, pp. 58-67. https://doi.org/10.11648/j.ija.20241202.15

[7] Pellicori, S. F. & Mark Evans: "The Shroud of Turin Through the Microscope", Archaeology 34, 34 (1981).

[8] Kelly P. Kearse, "Ultraviolet 365 as an Alternative Light Source for Detection of Blood Serum", J Forensic Sci, September 2020, Vol. 65, No. 5. https://doi.org/10.1111/1556-4029.14439

[9] Kelly P Kearse. "Environmental influence on blood serum detection using ultraviolet 365", J Forensic Sci Res. 2021; 5: 030-036. https://doi.org/10.29328/journal.jfsr.1001024

[10] Enza Fazio, Carmelo Corsaro, Domenico Mallamace, "Paper aging and degradation monitoring by the non-destructive two-dimensional micro-Raman mapping", Spectrochemicaacta, Part 1 A, Molecular and Biomolecular Spectroscopy, 228 117660 (2020).

[11] J. Łojewska, I. Rabin, D. Pawcenis, J. Bagniuk, M. A. Aksamit-Koperska, M. Sitarz, M. Missori & M. Krutzsch, "Recognizing ancient papyri by a combination of spectroscopic, diffractional and chromatographic analytical tools", Scientific Reports | 7: 46236 | https://doi.org/10.1038/srep46236

[12] Pellicori, S. F., "Spectral Properties of the Shroud," Applied Optics 19 (12), pp. 1913-1920 (1980).

[13] Kearse KP. "Evaluation of the potential role of skin contact and transfer in the Maillard hypothesis of image formation on the Shroud of Turin". J His Arch & Anthropol Sci. 2023; 8(2): 73–81. https://doi.org/10.15406/jhaas.2023.08.00277

Biography

Samuel Pellicori is an independent consultant in optical technology with specialties in thin film coatings, spectroscopy and space-borne instrumentation technologies. He earned BS physics and MSc optical sciences degrees from University of Arizona, Tucson. He has consulted for more than 140 clients, including universities, NASA, DoD and many large and small companies in the US and overseas. He has served as a peer reviewer for optics journals and proposals, and as P1 or Co-Pi on several SBIR projects. Published more than 40 peer-reviewed journal papers. As a member of STURP, he participated in spectrophotometry, UV fluorescence photography and microscopy data collection during the 1978 investigation.

Research Field

Samuel Pellicori: Investigation of the Turin Shroud and stimulations., Optical thin film designs, materials, and technologies., Spectrometer, polarimeter and scatterometer engineering., Materials studies for space radiation environments., Applicable experience over wavelengths UV to IR., Planetary and earth remote sensing instrumentation development.