Color and Intensity Analyses of the Shroud of Turin

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At a distance the Shroud of Turin appears as a long rectangular yellowed cloth. Closer in, many different types of discoloration patterns can be discerned that, for the most part, are subtle variations in intensity of the cloth's general yellow color. Certain patterns are recognizable to the unaided human eye such as the body image, scorch marks (from the 1532 fire), water stains, etc. Blood marks are also recognized because of their generally red color and greater intensity.

The problem in studying such image patterns on the Shroud is compounded by the fact that these patterns lie in a very restricted range of both color and intensity. Often, studies of image patterns are conducted on only one of these variables, such as the familiar black and white negative image provides. In this representation, the color variable is completely removed and we are left with only the intensity variable to discern and study the various image patterns. Indeed, one of us (Jackson) studied suspected correlation of intensity with cloth-body distance in order to gain insight into the image formation mechanism (Ref. 1).

Without color characterization, the blood features can be distinguished only on the basis of intensity. While this might be acceptable for most blood marks, such as the dense side and wrist wounds, it is not possible for blood marks of the same intensity as adjacent body image features.

As a second example, consider a computer representation of the Shroud image produced by Avis, *et al* (Ref. 2) in which color characteristics of the image are, in essence, expanded into a broader region of color space. Here, because there is no obvious correlation with intensity, we might consider this image to be a color-only representation.

Recognizing that both intensity and color are important image characteristics, we have been led to develop a methodology that allows both color and intensity to be studied together rather than separately as in the above examples. We propose that this can be accomplished by tagging each and every point on the Shroud with an index which depends on both color and intensity. In so doing, we have a considerably more powerful way to discriminate between subtle image features and to see certain relationships that are otherwise not possible to discern. For example, features that have the same intensity, such as the blood and body features described above for the black and white imagery, would nevertheless be considered different because the blood would have a redder color index than the body feature.

In this paper, we present our technique that we believe offers considerable potential in studying image features on the Shroud by utilizing a simultaneous color/intensity discrimination of image features. As opposed to other image analysis techniques that use only a single photographic recordation of intensity, our technique requires simultaneous study of three photographs made in different color regions. We use one photograph to define image intensity and the other two to define the color. Because this implicitly involves more information (i.e. three images instead of one), we expect that new insights about the Shroud could be obtained with proper utilization of our technique.

Methodology

The procedure begins with a display of the data which consists of pixels scanned from original photographic negative pictures of the Shroud. The photographs were created during the 1978 STURP expedition to study the Shroud by Devan and Miller (Ref. 3). The selected photographs consisted of the separate red, green, and blue filtered images of the frontal head and torso region of the shroud. The filters used allowed light transmission for the wavelengths 370-500 nm for blue, 500-575 nm for green, and 585-750 nm for red. These photographs were scanned for us by Analytical Surveys Inc. of Colorado Springs, Colorado, USA using a high fidelity microdensitometer. This resulted in data sets consisting of 8-bit pixel data, hence encoding 256 levels for each color. The densitometer was set for all scans to record a value of 255 for the brightest red values, because red was deemed the brightest through visual inspection. The scan data was recorded on magnetic media suitable for reading by a desktop computer system.

An Apple Macintosh 7100/80 personal computer system was programmed to read, display, and manipulate the scan data. The first step consists of registering the three separate images. This involved a straight forward (though tedious) process of shifting each displayed image until corresponding pixels from each image are at the same display location. Fortunately it was found that no rotations or warping were needed, but mirroring the blue image vertically and horizontally was necessary as the blue photographic negative was inadvertently scanned in an inverted position.

It was immediately obvious from the "raw" display of the data that for a "true color" display, the relative intensities of red, green, and blue would need adjustment. Displaying a "true color" image is not necessary for this project, so no color adjustments were attempted. Another obvious feature of the displayed image is that the illumination of the cloth during photography was not uniform. The illumination pattern, however, was roughly rotationally symmetric about a central brightest point of the image and so a rather simple method of converting the data to correspond to a uniform illumination is possible. The method is similar to that employed by Avis, *et al* (Ref. 2). If the maximum pixel intensity l(r) is known for all pixels at radius *r* then the value I(0) is the maximum overall intensity. Applying the factor I(0) / I(*r*) to all image pixels then gives a uniform maximum brightness to the whole image. This procedure was accomplished by sampling image pixels at each radius, smoothing the scatter towards the maximum, and then least-squares fitting a polynomial to the resulting (*r*, l(*r*)) pairs. The results for each color are shown in Figures 1 through 3. Due to the radial nature of the fits, only the image within a circular limit remained viable for analysis as shown in Figure 4.

Using the illumination-corrected image we applied computer aided analysis. The analytical method employed was first investigated by Pellicori (Ref 4). A color-index plot of the data was made by evaluating for each pixel the red to blue intensity ratio and plotting that ratio versus the green intensity of the pixel relative to Cartesian axes. The color-index plot for our image data is shown as Figure 5. While no distinctive pattern is apparent, identifying the regions of the color-index plot with features of the shroud image will impart meaning to the results. The computer is programmed to display the image so that pixels which correspond to a selected region of the color-index plot will be displayed as pure white (255,255,255); note the example of Figure 6. Inversely, when the computer's display pointer is placed upon an image pixel, the color-index plot position for that pixel is reported and highlighted.

Application and Analyses

Let us now consider an example of how this technique could help clarify a potentially important issue concerning the nature of the Shroud image and how it might have been formed. In this regard we have been studying the effects color changes induced in linen by ultraviolet radiation.

One experiment (Ref. 5) consisted of irradiating a linen sample, hand-woven like the Shroud, with the 254-nanometer mercury line at approximately 1 milliwatt/cm2 for five days. This corresponded to an accumulated dose of about 400 Joules/cm^2 or, equivalently $5(10^{20})$ photons at 4.9 eV/photon. It is noted that, while this short-wave ultraviolet radiation does not lie specifically in the vacuum ultraviolet, its photon energies are sufficient to induce photochemical reactions in cellulose.

After illumination with ultraviolet, it was noted that the exposed area was bleached relative to the background cloth. When exposed to long wave ultraviolet radiation the bleached area also fluoresced more than the background. The cloth sample was then aged in an oven at 150°C for up to 18 hours. At various times the sample was removed and a reflectance spectrum recorded from 420 to 680 nm at 20 nm intervals (excluding 460 nm because of spectrometer problems at that interval). Spectra were recorded for both exposed and unexposed (background) areas. Visually, the bleached region discolored faster than the cloth background and took on a brownish color, similar to that of the Shroud image. The brownish color was restricted to the surface fibrils since they had been exposed to ultraviolet radiation, which is absorbed over fibril to sub-fibril distances. By inference, according to Arrhenius extrapolations, the same phenomenon should occur at room temperature, but over a much longer time scale. Thus, if ultraviolet radiation photo-imprinted the image into the Shroud fabric, subsequent, natural aging would have reversed the initial bleached image into the brownish appearance it has today. During this reversal, there should have necessarily been periods when the image was not visible to the naked eye.

Figures 7 and 8 (from Ref. 5) show the reflectance measurements for the background and UV exposed regions of the cloth sample during the oven bake, with corresponding curves for each sample taken at the same aging times. The initial reflectivity of the sample is greater than that of the background which accounts for the observed «bleached» appearance. However, with time, the reflectivity «caught up» with and passed the background, which also browned with time, but not as fast.

Figure I0 (from Ref. 5) represents the same experimental data in our colorspace format where the color ratio of the spectral curves (i.e., reflectivity at 680 nm to that at 440 nm) is plotted against mid-band color reflectivity (at 550 mn). From this representation we learn that the UV and background regions of the sample age along different color curves. Note that for a given midband reflectivity the UV discoloration is always somewhat redder than the cloth background. The reason for the slight redshift is due to the initial offset caused by the bleaching of the cloth by the ultraviolet dose, which persisted throughout the aging experiment. Thus, once the aging experiment commenced, the UV and background regions tracked along nearly parallel paths in our color space representation.

If this redshift phenomenon is generally characteristic for UV exposed cloth, then we might be able to test the hypothesis that ultraviolet radiation produced the Shroud image by plotting reflectivity measurements made directly from the Shroud in our color space. Figure I0 shows some tentative results in this regard. We see two closely spaced but distinct regions indicated in the color space. The upper region pertains to a region of the facial image while the lower region pertains to a fire scorched region near to the facial image. This is consistent with our aging experiments on UV altered linen and might therefore indicate a radiation mechanism, different than simple scorching, for the Shroud image. Clearly, precision data is required for clarification of these potentially important results.

The Need for New Image Data

Having done the aforementioned analysis with the data presently available, it is apparent that the results only hint at what is possible. What is needed is better data such as can be obtained with present-day digital cameras. Such data would eliminate the need for the illumination correction, give more dynamic range to the colors, eliminate the registration problem, and provide correct relative intensities for the separate color data. Because the methods and tools of analysis described and developed here show much promise, not only for Shroud studies but for other image artifact examinations, it is imperative that a new digital data collection system be implemented and applied to the Shroud. The immediate availability of this computational tool for data analysis can allow onsite «spur-of-the-moment» decisions. ■

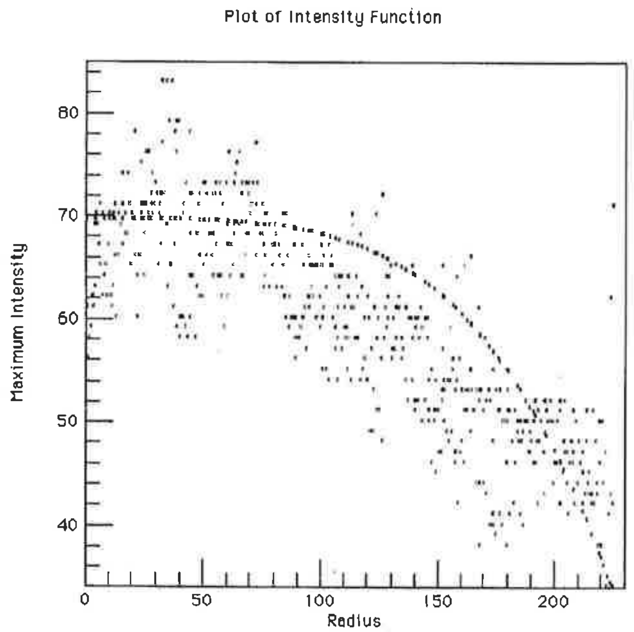

Figure 2

Blue Intensity Function

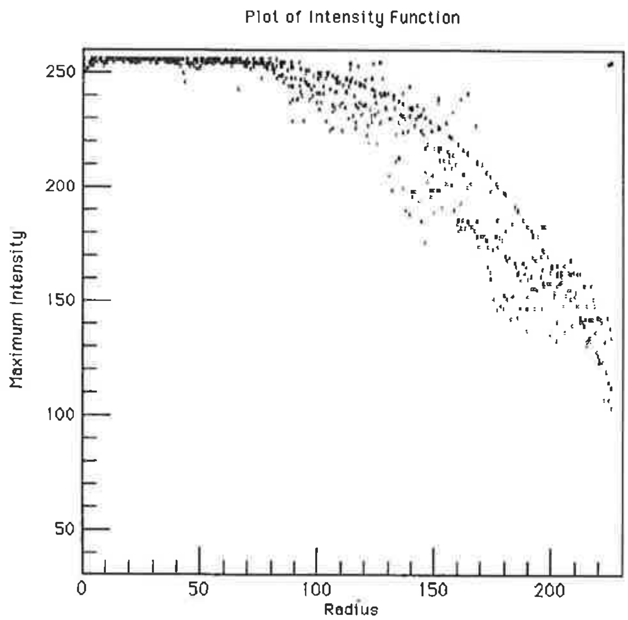

Figure 1

Red Intensity Function

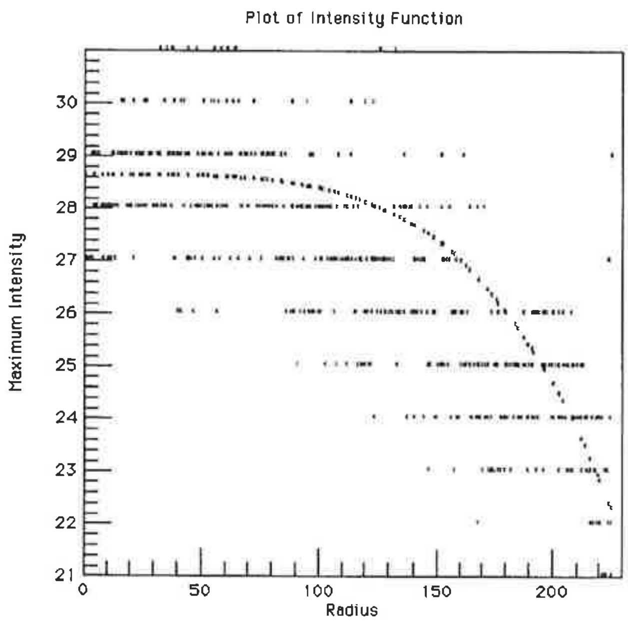

Figure 3

Green Intensity Function

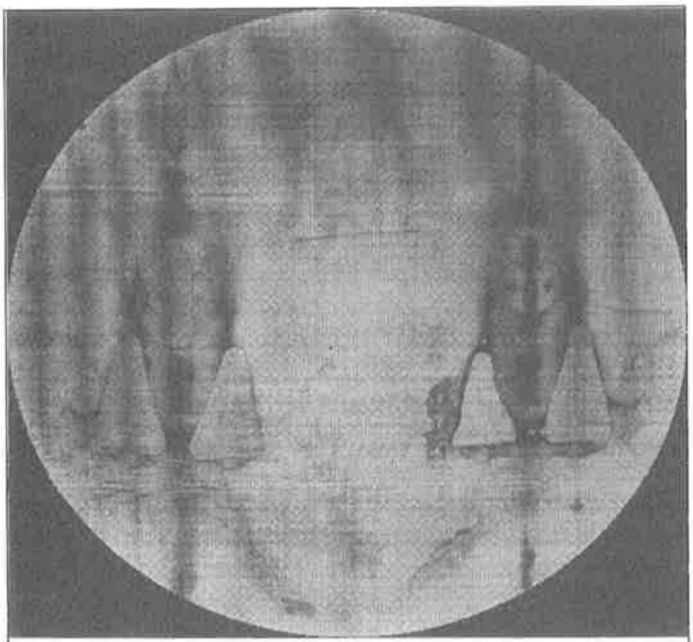

Figure 4
Illumination Corrected Image

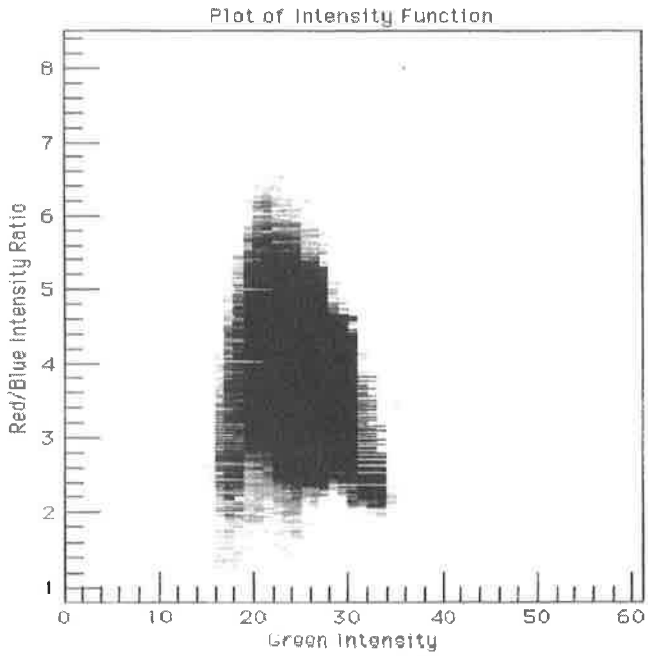

Figure 5
Color Index Plot for Shroud Image

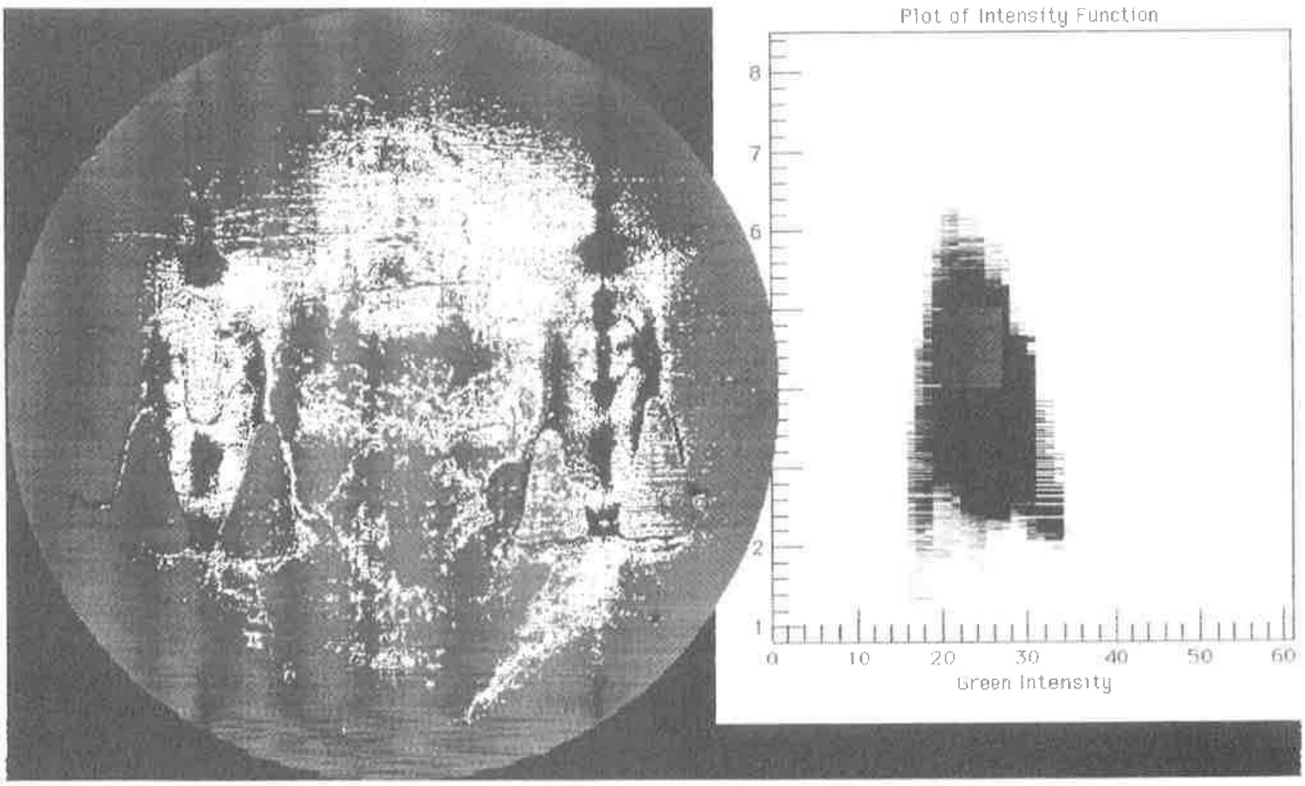

Figure 6
Example of Image Highlighting

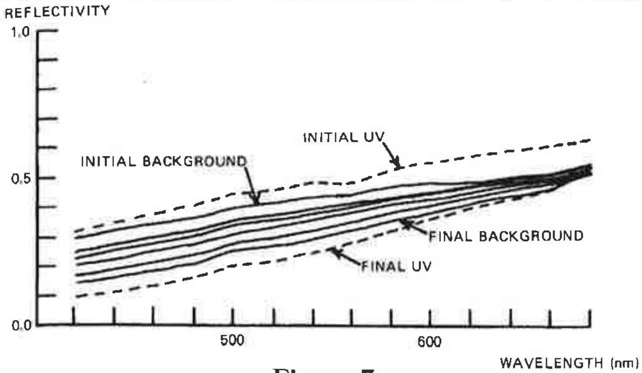

Figure 7

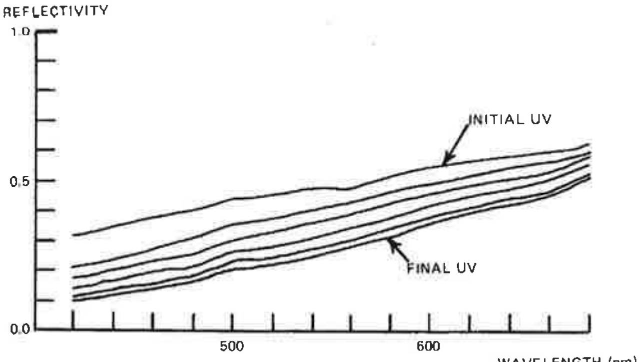

Figure 8

Absolute reflectivity versus wavelength for background control sample (C-1) and for UV presensitized sample (C-2). The six curves in each diagram correspond to the same times. The maximum and minimum curves for C-2 are drawn in C-1 for convenience.

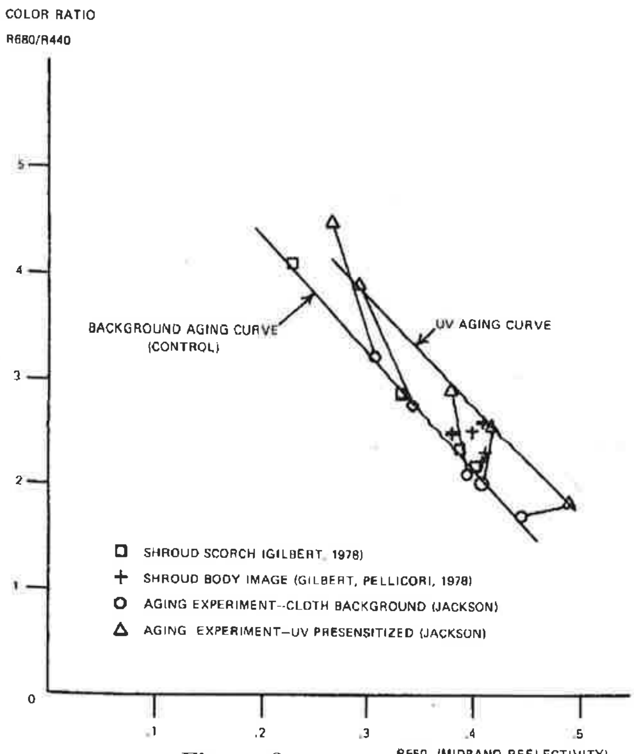

Figure 9

Color ratio (reflectivity at 680 nm to 440 nm) versus mid-band reflectivity (at 550 nm). Cross-lines connect experimental points corresponding to equal times. Note that UV sensitized sample moves along its color curve faster than the background cloth.

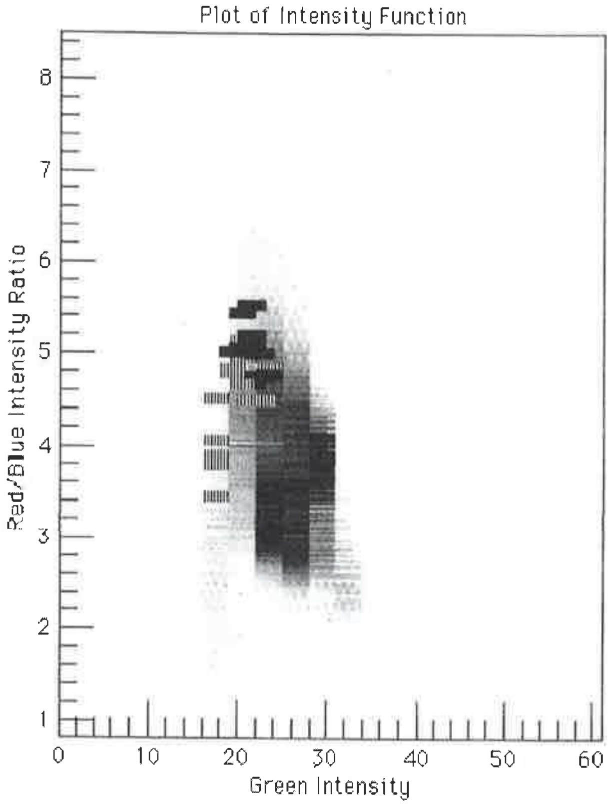

Figure 10
Example of "Redshift Measurement
The solid black regions of the Shroud image
while the lower shaded regions
(vertical lines) are for pixels located
in fire scorched regions near but not
in the facial region.

Références

1) John P. Jackson, Eric J. Jumper, and William R. Ercoline, «Correlation of Image Intensity on the Turin Shroud with the 3-D Structure of a Human Body Shape», *Applied Optics*, Vol. 23, pp. 2244, July 15, 1984.
2) C. Avis, D. Lynn, J. Lorre, S. Lavoie, J. Clark, E. Armstrong, J. Addington, «Image Processing of the Shroud of Turin», *IEEE*, pp 554-575, 1982.
3) Don Devan and Vernon Miller, «Quantitative Photography of the Shroud of Turin», *IEEE*, pp. 548-551, 1982.
4) S.F. Pellicori, «Spectral Properties of the Shroud of Turin», *Applied Optics*, Vol. 19, N°12, pp.1913-1920, 15 June 1980.
5) John P. Jackson, «Is the Image on the Shroud Due to a Process Heretofire Unknown to Modern Science?», *Shroud Spectrum International*, N°34, pp. 3-29, March 1990.

Question à K. E. Propp :
Je n'ai pas bien compris l'objectif exact de cette étude.

Réponse :
Ces données permettent de montrer certains détails, de développer et soutenir certaines thèses et de valider certaines méthodes, comme par exemple la méthode avec l'emploi des UV dont j'ai parlé.

Commentaire:
Je voudrais soulever l'intérêt de cette approche. En tant qu'astrophysicien pendant 25 ans, je sais l'importance de ces diagrammes colorés qui permettent de montrer des tout petits détails de couleurs. Peut-être pourra-t-on ainsi revenir sur la découverte des lettres et arriver à plus d'information.

Commentaire de J.P. Jackson :
J'aimerais préciser. A chaque pixel de l'image, on applique en quelque sorte deux labels : un label de couleur par les images rouge et bleue, et un label d'intensité par l'image verte. Ce peut être très utile et cela permettra, avec une bonne résolution, de reconnaître certaines caractéristiques, certaines régions. Si on alterne entre l'image du linceul et le diagramme de Rossel, on arrive à être très efficace et à créer un type d'image nouveau. Si nous avions de bonnes photos, nous progresserions très vite.

Question :
Avez-vous vu des différences entre les brûlures et les autres marques ?

Réponse:
Nous n'avons pas analysé de différence particulière entre les différentes marques ou stigmates. Ce sera encore difficile avec les données dont nous disposons.

Commentaire de G. Kaplan :
La grande différence observée entre la région faciale et le reste du corps a peut-être un rapport avec la thèse du Mandylion, selon laquelle seul le visage aurait été exposé.

Réponse de K. E. Propp :
La différence de rougeur entre le visage et le reste du corps est un point très intéressant. Nous n'avons pas cherché réellement à résoudre ce problème.

Commentaire de J.P. Jackson :
Si on prend deux images du visage et d'une autre région et si on se réfère au diagramme de Rossel, on se rend compte qu'il y a des différences d'intensité et que le visage est beaucoup plus coloré en rouge, même lorsque les brulûres sont comparables. Nous ne connaissons pas l'explication. S'il y avait un vieillissement différent selon l'endroit, on le détecterait.

Commentaire de K.E. Propp :
Cela confirme ce que je disais. Les nuances sur les photos traduisent des compositions chimiques différentes, donc l'analyse rouge/vert/bleu ne suffit pas toujours. Lorsqu'on regarde l'absorption en large bande et la composition chimique, ce n'est pas très simple au point de vue chromatique, cela prête à confusion. Il faut donc avoir des largeurs de bande qui soient à même d'appréhender les phénomènes.

Commentaire de J.P. Jackson :
Si on veut faire de la chimie haute résolution et de l'analyse spectrale, c'est difficile. Si on pouvait extrapoler sur le multidimensionnel en couleurs avec 15 nm de résolution, on pourrait sélectionner certaines régions et procéder comme nous l'avons suggéré.

Analyses de couleur et d'intensité sur le Suaire de Turin

Nous présentons notre analyse de l'image du Linceul qui utilise une méthode introduite par Pellicori, méthode qui classe les caractéristiques de l'image selon la couleur et l'intensité. Cette procédure sensible nous permet de discerner des traits subtils qui autrement ne peuvent pas être distingués par l'oeil humain. Cette technique est particulièrement appropriée au Suaire parce que les caractéristiques du corps, des brûlures, des traces d'eau et de certaines taches de sang présentent des nuances de noircissement et de couleur similaires. Un résultat important de cette étude est de révéler des différences subtiles entre l'image du corps et des régions brûlées toutes proches. Nous faisons des commentaires sur les implications possibles de ce résultat significatif sur la formation de l'image. Nous présentons aussi une nouvelle façon de visualiser images et taches sur le Suaire en utilisant les résultats de notre technique. Comme les méthodes et les outils d'analyse décrits et développés ici sont très prometteurs, il est impératif de mettre sur pied une nouvelle base de données numériques et de l'appliquer au Suaire.