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QUANTITATIVE PHOTOGRAPHY OF THE SHROUD OF TURIN

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ABSTRACT

This paper summarizes the results - primarily in the form of photographic images - obtained by the group of scientific photographers and image processing scientists who comprised the technical photography team for the Shroud of Turin Research Project (STURP). More specifically, the paper summarizes the tasks of objective definition, experimental design, planning, preparation, rehearsal, etc. which culminated in the acquisition of approximately one thousand documented images of high photographic quality, many suitable for computer-oriented image analysis, under the difficult in-situ conditions imposed by by the size and delicacy of the Shroud. Finally, this paper presents a summary "catalog" of the images obtained (see Table 1), according to format, camera/lens system, filtration, film, lighting, etc.; along with some example reproductions of the imagery.

VISUAL PROPERTIES OF THE SHROUD

Were it not for several perhaps unique visual properties, the Shroud might well have remained in the near total obscurity which characterized its history from the first mention of its existence in the fourteenth century, through the time it was first photographed in 1898 by Secundo Pia, a lawyer by profession and a respected amateur photographer by avocation. His photographic negatives were to vigorously reopen the issue of the origins and nature of the Turin Shroud. Pia's negative images dramatized one of the several visual properties of the Shroud which removed it from the historical obscurity in which it had remained since branded as a "cunning painting" by Pierre d'Arcis, bishop of Troyes, whose diocese included the small French village of Lirey, site of the earliest historical reference to the Shroud.

What Pia's negatives revealed was the fact that the Shroud takes on a life-like, well-resolved, subtly shaded photographic "print-like" quality when seen as a photographic negative image. Consequently, as illustrated by Figure 1, the actual image on the cloth must have the grey shade reversal properties of a photographic negative. This discovery, in and of itself, elevated the Shroud from relative obscurity to the object of sometimes passionate curiousity and investigation which it has since become.

As a result of such investigations, several other "unusual" visual properties of the Shroud have emerged (explanation for which must form a crucial part of any understanding of the nature of the image):

As shown by Figure 2, the pattern of intensity variations of the image (as measured by densitometric scans of photographic negatives) appears to correlate with the (hypothetical) distance between the elevation contours of a human body and a cloth presumed draped over that body. That such a consistent correlation exists has been qualitatively shown : I.e., the image is most intense when the cloth-body distance is a minimum, and vica-versa. Moreover, the intensity fall-off is roughly consistent with cloth-body distance regardless of where on the image the comparison is made. The quantitative relationship, i.e., the mathematical form of the intensity/ cloth-body distance relationship is not known; it cannot be determined until the intensity parameter has been transformed into units other than film density (since "density" is a function of film exposure and processing rather than a physical property of the Shroud such as reflectivity or absorbtivity).

The apparent visual variations in Shroud image intensity appear <u>not</u> to be due to inherent coloration variation[1] in the discolored thread fibrils themselves, but rather due to variations in the areal density of more-or-less uniformly discolored fibrils. I.e., the apparent macro-scale shading variations observed on the Shroud are, in effect, due to "halftone" properties of the fine-scale image.

[1]Qualitative observation of photomicrographs suggests that fibril "darkness" variations are on the order of only a factor of two over samples obtained from various locations all over the body-image portions of the cloth.

Photomicrographs (see Figure 4) reveal that the image-forming discoloration is carried by only the outer few fibril layers of the bundles which comprise the linen threads used to weave the cloth. The body-image discoloration is surficial only and does not penetrate into the the threads. Similarly, the discoloration itself is generally restricted to the crowns of the weave and falls off on the side portions of the threads. Conversely, photomicrographs taken in the "bloodstain" regions show encrustations of particulate matter and patterns of coloration which do suggest deeper penetration as well as capillary flow around the curved portions of the threads.

The image is resolved down to features on the order of one centimeter scale: The crease between the lips is clearly apparent, as are the separations between the fingers. Furthermore, densitometric traces across the fingers show a fall-off pattern corresponding to the curvature from the tops to the sides of the fingers, rather than an abrupt ("top only") pattern which would perhaps be expected from a simple, cloth/body contact image.

The above observations comprise, in the main, those visual properties of the Shroud which are deemed "distinctive". In a sense, these properties are a part of the qualitative "results" of the several photographic investigations of the Shroud which have been performed to date. The discussion below relates the details of the 1978 STURP investigation: its specific objectives; the means by which these objectives were realized; and the photographic "data" which resulted.

DEFINITION OF OBJECTIVES

The initially-determined objective for a new set of photographic images of the Shroud of Turin grew out of the first attempts to use computer image analysis techniques to extract additional information from existing photographs (several-generation removed copies of original images). These early attempts, which preceded even the serious suggestion of a new investigation by one or two years, highlighted the fact that although of excellent visual quality, all existing Shroud images were fundamentally "snapshots" from the point of view of the requirements of quantitative image analysis. Adequate information describing the conditions of lighting and film processing which governed the film density patterns on the exposed negatives did not, to our knowledge, exist. Sensitometric information (in the form of density-wedge images) was apparently totally lacking. Thus the role of the existing images was fundamentally limited to that of recording the qualitative visual and geometric properties of the Shroud image. In this sense, there was no "scientific" photography of the Shroud.

It therefore became the initial objective of the photography team to obtain a series of sensitometrically calibrate images which would ultimately take advantage of the fact that film is essentially an energy sensor (it is a feature-geometry sensor only by virtue of its spatial energy intensity recording capabilities). This in mind, the basic requirements for quantitative photography are straightforward (at least in concept):

The camera/object distance must be accurately known.

The film, light source, filtration, exposure combination must provide a range of reflected energy intensity within the latitude of the film's density vs. exposure response range, ideally in the linear (gamma = 1) portion of this response so as to optimize spatial energy gradient resolution. The film, etc. combination must be capable of response over the desired spectral band of the anticipated filters - in this case from near UV to deep red.

Perhaps most important (and most notably lacking in previous photographs), a means must exist to transform the energy response parameter recorded on the film -- i.e., the density of the photographic negative -- to a "physical" parameter (just which parameter is not necessarily known in advance).

For Shroud photography a reflectance wedge was fabricated consisting of fourteen steps ranging from 89% white light reflectivity for the brightest step to 1.3% for the darkest step. This wedge was photographed and processed under the same lighting/ filter, etc. exposure conditions as each series of actual images so as to provide a known calibration of the system's energy response. In addition to the grey scale step wedge, a Macbeth Colorchecker color rendition chart was photographed along with each series (different filter) of Shroud photographs.

Another level of objective definition had to do with geometric resolution -- the degree of spatial detail discernable on the film. The most stringent criterion developed for spatial detail assumed that the film would be scanned by a microdensitometer with a spot size on the order of 25 microns (0.001 inches) in diameter on the film, and that it was necessary to resolve at least one such spot on each thread diameter (about 250 microns). Thus a reduction factor on the order of 5:1 was established for the most resolved set of images. As described below (Table 1) other, more spectrally resolved, image series were taken at lower magnifications.

The final level of objective definition involved the selection of other photographic techniques which would provide qualitative supporting information for the analytical chemistry experiments (UV fluorescence, x-ray fluorescence, infrared and visible spectroscopy, tape sampling, etc.). Three specific elements of the photographic coverage were identified on this level and incorporated into the overall photo plan:

Large format white light color photography.

Black-and-white and color UV fluorescence photography.

Color photomicrography.

All of the above objectives were accomplished. The successful attainment of these objectives, especially in view of the fact that the actual in-situ conditions and limitations could not be well defined in advance, was due to an extensively worked out and rehearsed photo plan. This plan, as described below, involved careful attention to camera and film selection as well as considerable attention to the problems of obtaining a large number of accurately positioned (registered), focussed and exposed images in an unknown (but assumed relatively short) period of time.

PHOTOGRAPHIC COVERAGE PLAN

After much film testing a relatively new film, KODAK SO-115, was selected as the film to be used for all black-and-white photography. This film was judged to have the best combination of speed (ASA 100); resolution (300 line pairs/mm); grey scale resolution (gamma = 1); and panchromaticity. Additionally, special high-gamma Polaroid film (P-665) was supplied by the Polariod Corporation. This film was most useful in pre-determining exposures for the various filters planned for use in Turin, since its spectral sensitivity and grey scale resolution could be consistently related to the SO-115 film during a series of pre-Turin tests using a facsimile of the Shroud. This same film was then used in Turin to establish the exposure range for the SO-115 film.

Images intended for subsequent digitization and computer image analysis were obtained in the three formats outlined below:

1) Photomosaic coverage at 5.6:1 reduction on 70mm film. As discussed above, this magnification resolved at least one 25 micron diameter spot across the 250 micron threads. Each image covers a region 31-32 cm square on the Shroud; images were spaced 30 cm apart so as to provide slightly overlapped coverage. Figure 3 indicates the mosaic image locations. Red/green/blue color separation images were obtained. To ensure proper registration, filters were mounted on a "wheel" so that all spectral exposures could be rapidly obtained at each of the 60 camera positions required for the full mosaic.

2) Spectrally resolved "quad" photomosaics. This coverage consisted of multiple series of four images (at 22:1 reduction); each image covered an area about four feet square on the Shroud. Filtration consisted of a series of narrow band (about 100 angstrom) interference filters covering the waveband from near UV to deep red. (See Table 1).

3) "Octo" mosaics (see Figure 1) consisting of multiple series of eight images each 53.3 cm square, taken along the central portion of the Shroud. Filtration included white light (black-and-white film), narrow band, near UV, and red/green/blue color separation. A standard (white light) color series was also taken in this format. The "octo" mosaic format was also used for UV fluorescence series both on black-and-white (SO-115) and color (KODACOLOR II) film. UV images were obtained by filtering the output of two crossed field (45 degree angle) 200 watt xenon strobes through liquid filter cells consisting of one cm path length of inorganic salts of transition element metals[2] held between a pyrex window on the light source side and a Corning 9863 visible-absorbing, UV transmitting filter glass on the other side. The filter cells transmitted radiation in the waveband from 335 to 375 nm while absorbing other wavelengths. The camera was filtered with a Hoya 142 barrier filter (which blocks wavelengths below 400 nm) to eliminate reflected UV.

Photomicrographs on 35 mm (KODAK Ektachrome slide film) at magnifications ranging from 1 - 30X. (See Figure 4 for an example). A Wild microscope/camera system was used for these images. Color slides of specific image areas corresponding to background cloth, body-image areas, "bloodstain" regions, light and heavy scorch regions, and waterstain regions

[2] 80% $CoSO_4$; 15% $CuSO_4$; 5% $NiSO_4$.

were obtained with this system . (Other experiments using x-ray fluorescence, spectrometers, etc. obtained data in the same Shroud locations).

The logistics problems of obtaining the large number of photographs described above were solved by means of the specially designed camera mounting rail shown in Figure 5. The long axis of the rail was positioned parallel to the Shroud mounting frame. As shown by Figure 3, the Shroud was mounted such that the body image was along the horizontal with the frontal image extending right from the center.

CATALOG OF IMAGES

The "results" of the photographic coverage of the Shroud consist of on the order of one thousand images of various formats, films and spectral content. Table 1 below summarizes this coverage. This table is essentially a "catalog" of the scientific photographic imagery of the Shroud of Turin obtained by the STURP examination.

To date much of the quantitative aspect of the image analysis remains to be performed. Computer tapes containing digital information from some of the images have been generated by the Jet Propulsion Laboratory and some color enhancement and multispectral analysis work has been carried out using this digital information. The UV fluorescence and photomicrographic coverage has been more thoroughly examined; and observations and conclusions from this imagery have been published. Some of the Shroud's "visual properties" mentioned earlier in this paper were discerned from such efforts. Similarly, analysis of the color UV fluorescence images has begun to yield some interesting results, including:

The body image is fluorescence-quenching relative to the background (non-imaged) regions of the Shroud.

Fluorescence in "bloodstain" image regions is distinctly quenched. Some of the "bloodstain" images are surrounded by lighter (less quenched) "halos" possibly due to blood serum which retarded the image formation process.

Scorch regions <u>do</u> fluoresce, emitting reddish-brown light. Laboratory scorches made in oxygen-depleted conditions fluoresce similarly. (The fact that the body image does <u>not</u> fluoresce casts some doubt on "hot statue", etc. scorch hypotheses proposed for Shroud image formation.

FUTURE TASKS

Obviously, much work remains to be done on the analysis, particularly quantitative analysis, of the Shroud photography. With the analytical chemistry work having reached some definite conclusions, one area of such analysis has become more clearly defined: I,e., as Shroud image formation hypotheses are tested by laboratory simulation using controlled (calibrated) formation mechanisms, the "mapping" of the Shroud photographs into the physical units of the laboratory mechanism (via the calibrated reflectivity step wedge) represents a viable means to "observe" the results of the hypothesis in terms of the spatial distribution of the presumed image-forming agent required to form the actual Shroud.

This, and other avenues of quantitative and qualitative analysis of the Shroud photography should continue to provide insights into the enigma of the Turin Shroud.

OBJECT SIZE	NEG. FMT	MAG. RATIO	FILM	CAMERA	LENS	LIGHTING	FILTERATION Center freq. in Angstroms
120 cm quad section	6X6 cm	22:1	SO 115	EL HASS ELBLAD	80mm	Norman 202 200 watt-sec	4398, 4490, 5506, 5987, 6233, 6530, 6666, C, R/G/B/
533 cm octo section	" "	88:1	" "	" "	100mm	" "	4398, 4990, 5506, 5987, 6233, 3550, C, R/G/B/ color
533cm octo UV Fluores- ence	" "	88:1	Kodacolor 400 5075	" "	80mm	" "	Excitation: 3550-3750 A Barrier: 4110 A
30cm section	" "	5.1:1	" "	" "	150mm	" "	R/G/B SEPERATION FILTERS, 3866
photomicro	35mmm	1:1-1:30	EKTA-CHROME	" "	ZOOM	Sun Pac 90 90 watt-sec	NO FILTERATION
150X120 cm section	8X10 in	6:1	" "	SINAR 8X10	330mm	Incandescent 1000 watt	" "
20X25 cm face section	" "	1:1	" "	" "	" "	" "	" "

Table 1: Photographic Coverage Summary

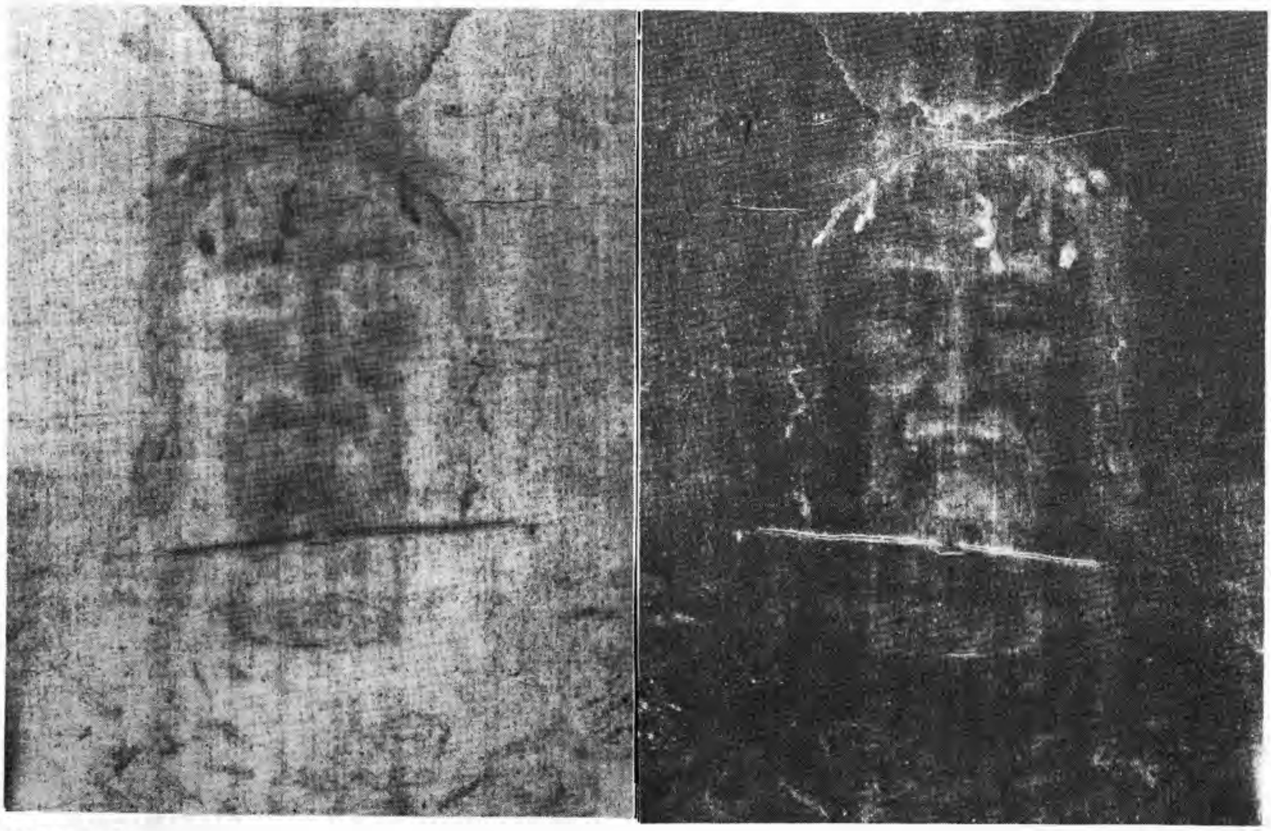
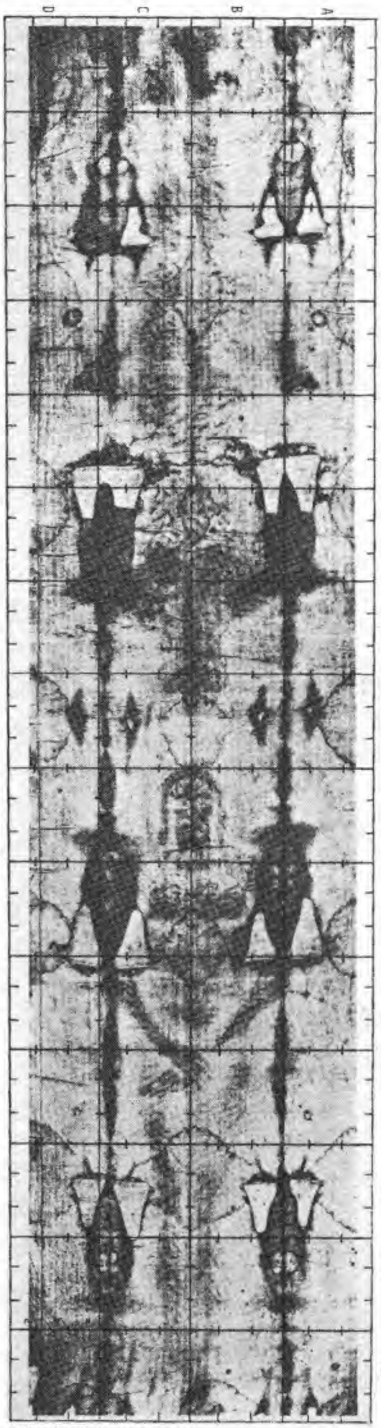


Figure 1:

SHROUD OF TURIN

Face Section, Positive-Negative Comparison
Photographed by Vernon Miller©, Brooks Institute
STURP, October 10, 1978 Turin, Italy



MASTER REFERENCE MOSAIC (M.R.M.)
1978 UNITED STATES CONFERENCE OF RESEARCH ON THE SHROUD OF TURIN.

Figure 3: 30cm Mosaic

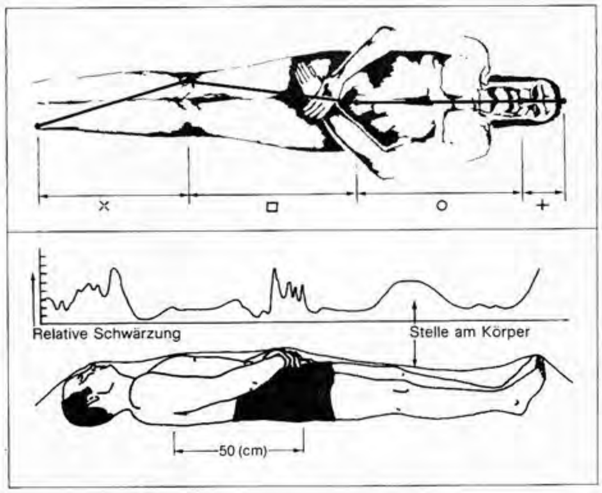


Figure 2: Cloth/Body Distance Vs. Film Density

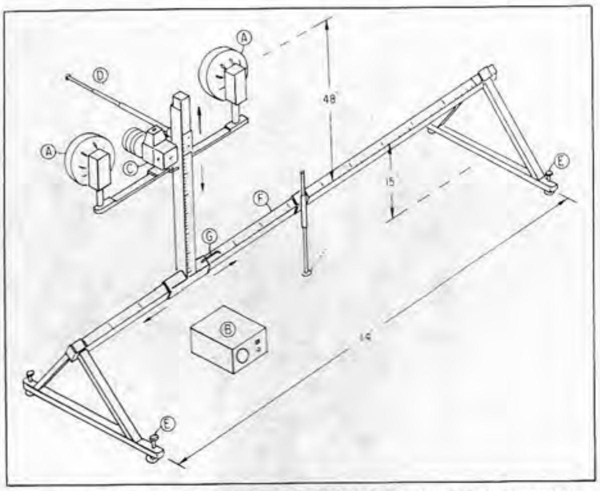


Figure 2—Camera and illumination positioned on support rail for indexing along the length of the Shroud and thus creating a complete mosaic of photographs according to the reference layout in Figure 3. A—Lamp heads (Norman 200 B) with liquid cell filter. B—AC power pack. C—EL Hasselblad camera with 70 mm back. D—Telescoping extension rod for locating rail equi-distant from Shroud frame. E—Leveling screws. F—Centimeter scale with indexing marked for predetermined positions. G—Adjustable sliding index pointer for starting sequence.

Figure 4: Camera Mounting Apparatus

Figure 5: Photomicrograph 30X, Body Image