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IMAGE PROCESSING OF THE SHROUD OF TURIN

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ABSTRACT

The task of analysis of the Shroud imagery has been undertaken at the Image Processing Laboratory of JPL. Initial application of digitization and calibration techniques provided a set of useful digital images. More specialized techniques, such as, registration, filtering and color reconstruction, have produced various enhanced photoproducts. By request, reduced data have been sent to other STURP researchers for analysis. Spectral classification studies are currently underway to mesh the chemical sampling data with the imagery.

INTRODUCTION

Digital image processing has been used to analyze the 1978 images of the Shroud of Turin. The same software (developed for NASA) which supports space exploration at the Image Processing Laboratory was directly applicable to the Shroud imagery. This effort was conducted as a part of the Shroud of Turin Research Project.

Most of this effort has utilized the set of lower resolution "Quad" images obtained in 1978. This set consists of four multispectral sets of images covering the entire Shroud. A microdensitometer was used to scan these negatives of the Shroud. This device is a precision instrument designed to digitize information recorded on film negatives.

The digitizing scan used a 33 1/3 micron square aperture and a 32 micron step allowing for a slight overlap of data. As each increment was digitized, the analog signal of light was recorded as a 10-bit data word. This allowed up to 1023 possible levels of density to be recorded from each 32 micron step. The digitized information was then transfered to magnetic tape. It could then go through image processing at a later date.

Correction for Reflected Brightness Distribution

The necessary first step of the task was to produce images which had uniform and consistent illumination. A model of the incident illumination had to be constructed in order to free the images from the bright central spot created by the nearby flash lamps. This model was created by stacking the four digital images in each spectral band and, at each pixel location, selecting the brightest pixel of the four images. Because the image on the shroud was always darker than the unmarked cloth, the resulting image was mostly free of body image (there usually being a clear place on one of the superimposed images at any arbitrary location). The residual body or burn image was eliminated by operating a large Median (1) filter upon the resulting image. This process produced for each color a smooth gaussian type image, Figure 1; bright in the center and darker on the borders which represented the reflected brightness distribution of an image-free cloth. Each image was corrected by dividing it by this brightness distribution.

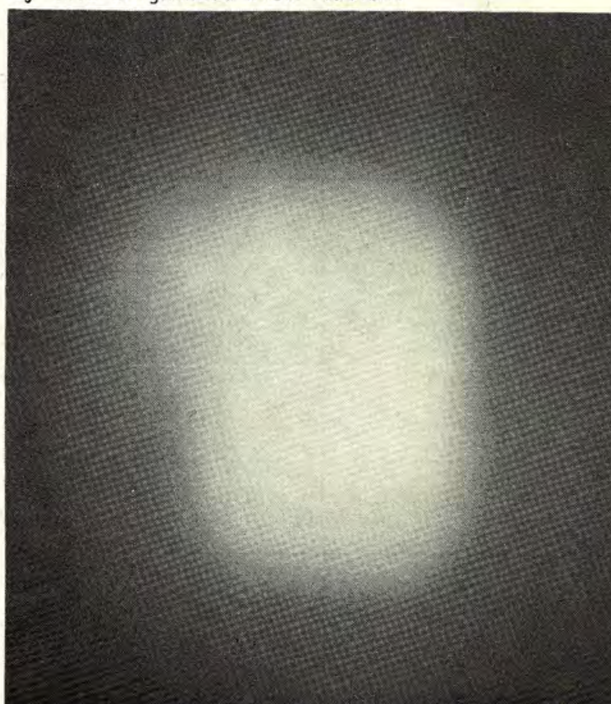

Figure 1. The reflected brightness distribution of an image-free cloth.

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Color Enhancement

The generation of color products was considered the most important image processing task. From a color enhanced, relative color display, the color (indicative of chemical composition) of different features of the image can be compared. From the set of "Quad" images (corrected for the illumination model), three spectral bands were selected representing broad band blue, green and red. After registration of the four sets of three images, the spectral bands were matched to produce histograms of equal variance. This assured that the colors produced would be equally distributed amongst all hues, providing optimal color discriminability for any chemical distribution analysis.

It was not useful to produce color images at this stage because of the high correlation between the spectral bands (the images were nearly multiplicative duplicates of each other), and would produce gray images devoid of discernible color. In order to enhance the color, each set of three images was converted to Principal Component space (2) by multiplying by the rotation matrix R which solved the eigenvector problem

$$R^{t}CR=C'$$

where C is the covariance matrix and C' is the diagonal matrix whose diagonals are the eigenvalues. The new images were spectrally uncorrelated. The color enhancement consisted of performing a non-linear contrast enhancement which transformed each new image such that it had a gaussian histogram which filled the dynamic range at 3 sigma. Retransforming the images through the reverse of the R matrix previously used, resulted in strong color enhancements preserving the original sense of the hues. An analysis of the resulting images revealed some global color shifts due to misalignment of the images prior to the illumination model calculation.

A second color version was produced which included an intermediate step to avoid the global color shifts. This step consisted of subtracting from each image, before the Principal Component calculation step, the local background calculated by a large Median filter. Some damage resulted from this step. However, the consistency of the colors was somewhat better.

Upon examination of these enhanced relative color images, it is apparent that colors differ due to the chemical distributions on the Shroud. Blood stains appear reddish and body stains are more yellow-brown. Clear cloth tends toward the other end of the spectrum and appears more blue.

Image's Three-dimensional Nature

Jackson, et al made a detailed study (3) of the three-dimensional nature of the Shroud image. They have reported that the density of the body image on the Shroud appears to be proportional to cloth-body distance at any point. Such a correlation has great implications for the theories of image formation mechanisms. Therefore, we applied independent image processing techniques in an attempt at confirmation.

The library of VICAR image processing applications programs contains routines which, when applied to topographic imagery, can illustrate the presence or absence of relief. Therefore, application of these routines to the digital Shroud data should enable one to decide if distance information (relief) is actually coded in the Shroud image. Given suitably prepared images, the decoding of relief present in the brightness information of an image can be accomplished in one step. This step is the application of the Derivative Filter (4 & 5), written by Gary Yagi of the Image Processing Lab in 1973.

This filter replaces the brightness value of any pixel by the magnitude of the brightness gradient for a given direction at that pixel. The output image appears as if the image was illuminated from a given direction. That is, artificial shadowing has been introduced.

Figures 2 & 3 illustrate the application of this filter to a topographic image of simulated Shroud data. This image is the result of the work of Dan Sheffer and Wayne Morek of Biostereometrics Laboratories. Using stereo imaging, they determined the surface topography of a cloth draping a person positioned like the person imaged on the Shroud. Treating topographic information as an image, (Figure 2), brightnesses are defined to be directly proportional to elevation.

Figure 3 shows the artificial shadowing introduced by the Derivative Filter. The result for this true relief image is obvious apparent relief. Any image whose brightness codes elevation will give such meaningful results.

The filter was applied to two types of shroud data for analysis. Both were positive images (background dark, image light) and were given optimum contrast stretches. In addition, a low-pass filter was applied to each to reduce high frequencies and fill in all brightness levels.

The first shroud data used was the blue "Quad" front torso image #7-07. As with the color task, this image has had the reflected brightness distribution model removed. This input is shown in Figure 4. The second image was a corrected version of the first described below. The correction described here is based on the assumption that the image does code the cloth-body distances, as Jackson and others have described.

Given that assumption, a more accurate image of the body would result if the draping effect of the cloth were removed. To accomplish this removal, it is necessary to have a cloth draping model and a correction function which can be applied to each pixel. The cloth draping model used is the image in Figure 2, described above.

To derive any kind of function correcting for cloth draping, several assumptions about the imaging mechanism must be made. First, we must assume that the points of the resulting image on the cloth relate only to points of the body directly below. Second, we assume that the initial body intensity is uniform. Third, we assume a power law function for the intensity at a given distance from the body. Jackson's work was not specific as to what function best fit their data.

If, at any point, the floor-body surface distance is B with an intensity I_0, then at the floor-cloth distance C, the intensity I is

$I=I_0(B/C)^n$.

Our unknown is B, so

$B=C(I/I_0)^{1/n}$.

In this case, C is the topographic image of the draped cloth (Figure 2), I is the actual Shroud image (Figure 4), and I_0, as we said before, is a constant. In addition, we pick for this effort N=2 (inverse square law).

Given all the inputs, the correction is easily applied to each pixel to give a floor-to-body distance map (body relief image), which is shown in Figure 5. This corrected image is our second input to the Derivative Filter.

Figures 6 and 7 are the filtered results for the uncorrected and corrected Shroud images. The fact that recognizable shadowed body images have resulted immediately implies that relief information is present in the Shroud image. This result even applies to the uncorrected image, particularly the head area.

A further confirmation of the encoding theory comes from the fact that the applied correction (which assumed the theory was valid) did, in fact, improve the apparent relief result. The shaded corrected image appears somewhat more body-like than the uncorrected. Instead of the chest area being flat

Figure 2. Topographic image of simulated shroud data.

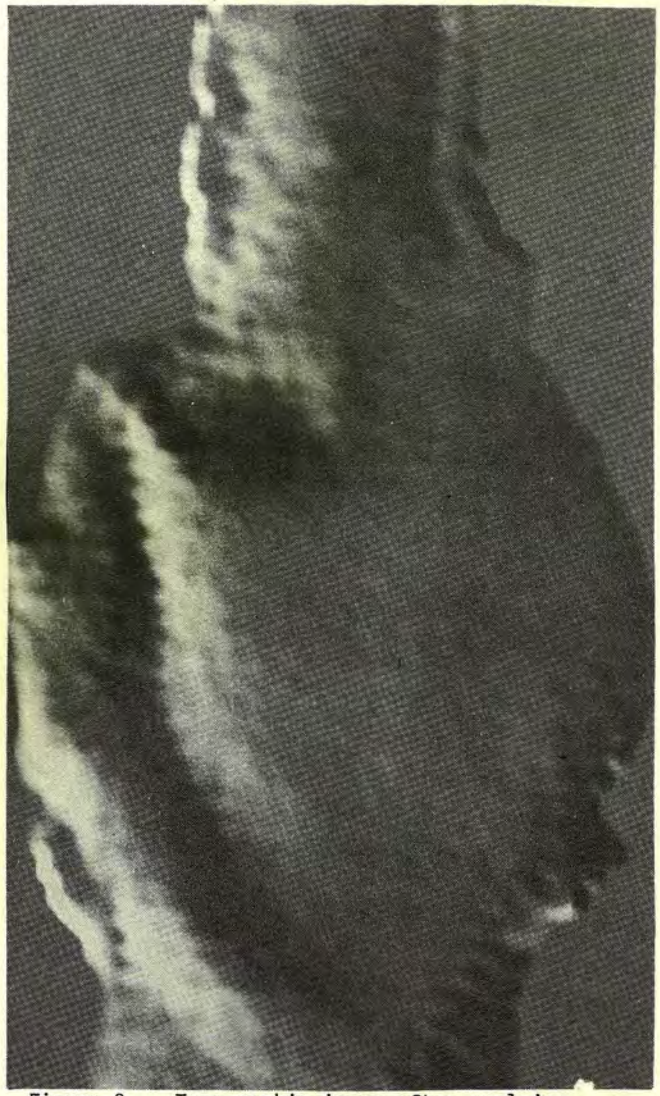

Figure 3. Topographic image after applying the Derivative Filter.

(because the cloth and body were everywhere in near-contact), the correction brings out some relief. Another example of improvement is that the hair no longer appears at the same elevation as the nose.

The theory described by Jackson, et al, that cloth-body distance is what is represented in the Shroud image appears valid. Those images corrected for cloth draping did have a more body-like appearance when artificial shadows were introduced. In addition, both corrected and uncorrected images acted more like topographic images than intensity images.

Spectral Classification

One possibility for future study of the Shroud imagery is multispectral classification to identify areas having similar spectral characteristics. The results of chemical composition tests on portions of the Shroud could be used as training sites to identify areas of similar chemical composition elsewhere in the Shroud. If the chemical substance has a distinct set of spectral characteristics, it might be possible to map its spatial location throughout the Shroud.

Given the spatially registered multispectral Shroud data, a given pixel represents the same physical location on the cloth in all channels. With its associated density values, each pixel, therefore, characterizes a certain portion of the Shroud spatially and spectrally. Therefore, knowledge of the spatial coordinates of a known chemical substance will train the computer to locate areas with similar spectral characteristics. First, the density values of these training site pixels would be summarized as statistics (indicating the range of density values)describing the substance in each spectral channel. Then, using these statistics as a guide, all channels of imagery can be searched for sets of pixels with density values within the proper range for that substance.

This search can be performed for any number of substances, as long as their training site statistics are sufficiently unique. Similar characteristics from training sites of different substances would cause the assignment of more than one chemical name to the same set of pixels. But, if the chemicals were spectrally differentiated, the multispectral classification process could provide a map of chemical composition throughout a Shroud

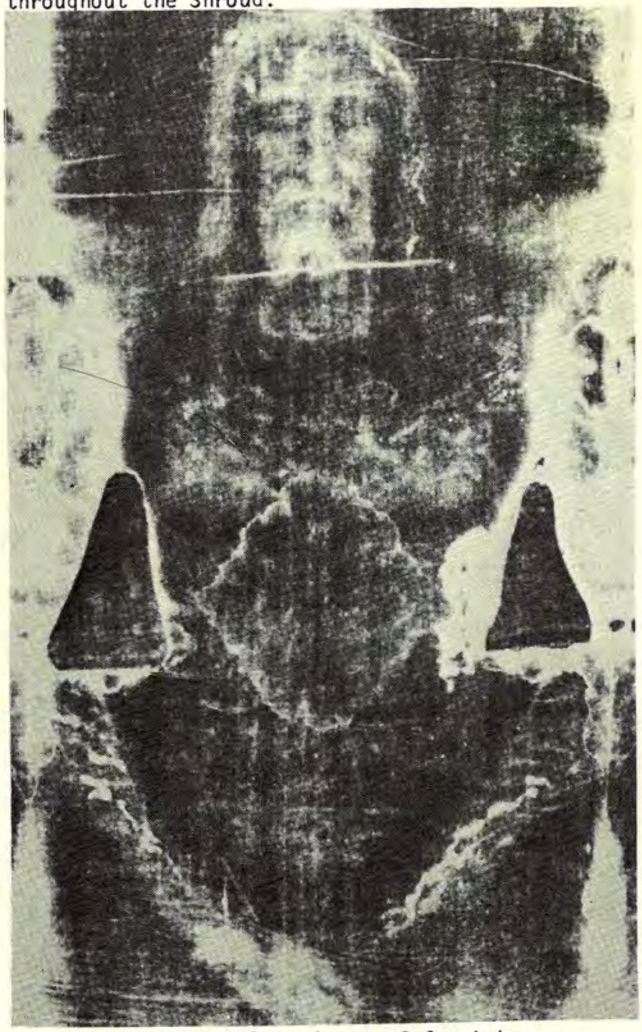

Figure 4. Blue filter image of front torso portion of the Shroud.

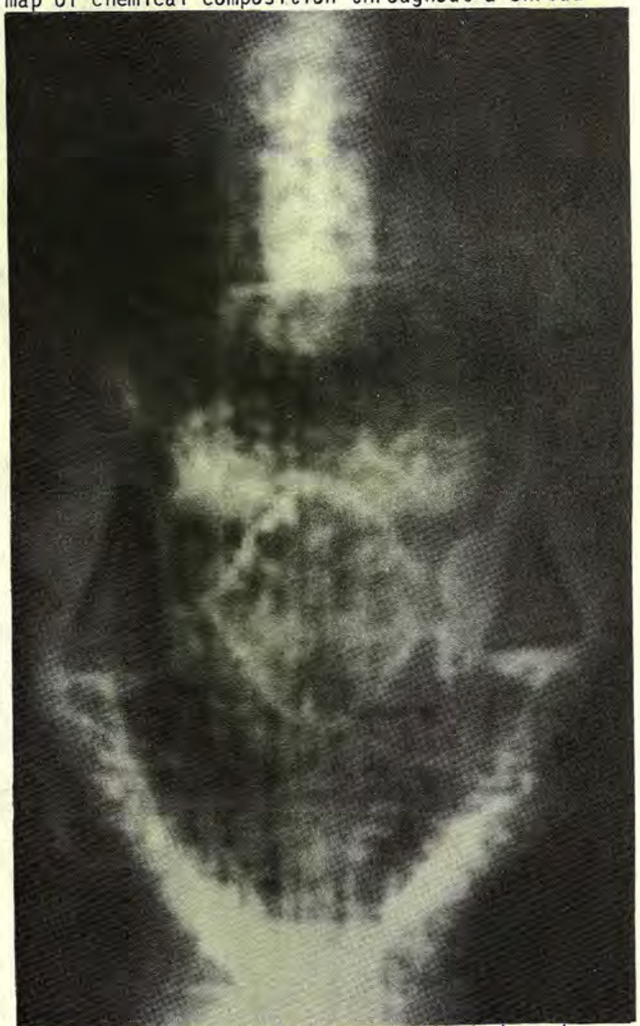

Figure 5. Topographic image of the body under the cloth.

image, based on training sites of the substances.

Acknowledgements

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(5.) Yagi, G. M., "VICAR Program SHADY", internal Image Processing Laboratory document, March 30, 1974.

Figure 6. The result of applying the Derivative Filter to the image in Figure 4.

Figure 7. The result of applying the Derivative Filter to the image in Figure 5.