Use of Digital Image Processing in the Analysis of the Shroud of Turin

Donald J. Lynn

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What is digital image processing, and how has it been applied to the scientific investigation of the Shroud? The following is an attempt to answer these two questions in a relatively simple manner. For more detailed explanations and examples of digital image processing technology, please refer to more detailed texts such as Castelman (1979) or Green (1983).

Digital Image Processing--What is it?

Webster's Dictionary (Guralnik, 1986) contains the following definition of an image: "An image is a representation, likeness, or imitation of an object or thing, a vivid or graphic description, something introduced to represent something else." Thus, an image contains descriptive information about the object or scene it represents. When presented as a picture or photograph, this descriptive information is displayed in a manner which allows the human eye and brain to visualize and appreciate the object or scene depicted.

Webster's Dictionary also gives the following definition of digital: "of or relating to data in the form of numerical digits." Combining the above definitions into simple terms, we can define a digital image as "a numerical representation of an object or scene.

But how is this done? As a simple example, let us take a black and white image and divide it into a number of boxes or rectangles of equal area. We will call each of these boxes a picture element or "pixel". We will then measure the average brightness or intensity of each of these pixels and assign to it a number in proportion to where the intensity lies between zero intensity (black) and maximum intensity (White); for 8 bit pixels, the allowable range of these intensities is from zero to 255. If we restrict the allowable numbers to only integers or digits, we have the basis for a "digital image." For a multi-color image we apply this process to each of the color components (red, green, blue, etc.)that we choose to use.

Thus, an array (two dimensional or greater) of numbers can be used to represent an object or scene. These numbers can then be manipulated via a digital computer to produce a number of different results: enhancements, color representations, geometric transformations, simulations, statistical analyses, etc. That is the technology called digital image processing.

What is Involved in Digital Image Processing?

There are three major steps involved in this process. The first involves transforming the scene, be it a photograph or drawing or live image, into a digital representation of the image. The second involves the computer processing or manipulation of the digital image in order to achieve some desired result. The third involves transforming the processed digital data into a form appropriate for display or interpretation.

Conversion of an image to digital data

In order to perform digital processing, it is necessary to put the data into a form, i.e. numbers, that a digital computer can accept and manipulate. In the case of the Shroud, the best existing images are primarily photographic negatives and positives. The digitization of these photographic images can be accomplished by scanning them with a precision scanning microdensitometer. In such a device, a small area on the film is imaged through a microscope lens onto a detector which measures the amount of light transmitted through the area. The resulting transmittance (or optical density) of that area (one pixel) is computed, expressed as a digital number and recorded. The scanner then moves to the next adjacent area and repeats the process. This procedure is repeated thousands or millions of times until the desired image area has been "scanned and digitized". A similar process is used to scan and digitize reflective images such as drawings or photographic prints.

In current solid state cameras, film has been replaced with solid state detectors in which the digitization of the image is accomplished as part of the image readout process. Thus the images output from these cameras are already in digital form.

Computer Processing

The next step in the procedure is computer processing. Basically this consists of reading the digitized data into a computer and subjecting it to a series of algorithms or computer programs which manipulate the data to extract or enhance specific information and format it for display or further processing. To the uninitiated, this sounds like a relatively straightforward process wherein one feeds the data into the front end of a "picture machine", pushes a button, and out comes a spectacular picture which shows all aorta of details and characteristics which were previously unseen. Unfortunately, it doesn't work that way. There is no single process which works equally well on all types of data and/or which produces the desired answers to the infinite number of questions which can be asked.

In reality, a typical image processing facility has available hundreds or thousands of different algorithms, each of which is designed to perform a certain function or set of functions on the data which it is given. The analyst may then select and apply these algorithms in a "mix and match" fashion until he or she produces a desired product. Thus, even though one starts with well-defined objectives in mind, the process of achieving those objectives can be a very arduous and time consuming task. In fact, some processes which sound very difficult, like frequency analysis, are relatively easy to perform; other processes which sound relatively easy, like cleaning up a picture, can be extremely difficult to accomplish. The Shroud pictures are, in fact, examples of images which are very difficult to "clean up" without destroying the quality and content of the images.

Displaying the Results

The third step in this somewhat simplified description is to output or display the results of the processing in a form that is best suited for analysis and interpretation. In most cases, this output is in the form of other images--either volatile images on a video monitor, or hard copy images such as prints or photographic products. The output may, however, be in the form of a graph or a printout of numbers, or a Fourier Transform, or recorded on digital disk or tape for dissemination and/or further processing.

In the output display process, the scanning/digitization process is reversed. That is, the digital value of each picture element is read by the output device and converted to an electron beam intensity (in the case of a video display), or to an optical beam intensity (in the case of a film recorder). Each display element is then exposed in proportion to the digital value of the corresponding picture element in the digital image. For color displays, individual digital images are required for each of the colors to be displayed (e.g., red, green and blue).

What Images of the Shroud Exist?

The primary sources of the imagery of the Shroud of Turin are:

--Secondo Pia's black and white photographs taken during the period Hay 25-28, 1898, (Loth, n.d.;2 Zaccone, 1991)

--Giuseppe Enrie s black and white photographs taken in Hay 1931 and in 1933, (Enrie, 1933/1938, 1936)3

--Gian Battista Judica Cordiglia's color photographs taken during the period June 16-17, 1969, (Judica Cordiglia, 1976; Frei, 1976)

--Judica Cordiglia s photographs taken on November 24, 1973, (1975) and

--STURP photographs and others taken during the period October 8-13, 1978 (see references in subsequent paragraphs).

Other sources include photographs taken by Professor Aurelio Ghio during the 1978 testing (1978, 1983), those taken by a team of photographers from Turin (Artom & Soardo, 1983a & b) during the 1978 testing, and some additional photographs which may have been taken by Enrie in 19334 (Curto, 1976, p. 65). On 22 and 23 November 1973, RAI-TV filmed a specially arranged, private display of the Shroud and subsequently aired the detailed exposition of the

Shroud in black and white (Pollicita, 1976). Video recordings were made during the taking of samples for C14 dating on 21 April. 1988, but their value for anything other than documentation remains to be determined. It is not known whether any other controlled images of the Shroud exist or are available for analysis. Any additional information in this regard is welcomed by the author.

Although Pia's images are of low resolution and relatively poor quality compared to later imagery. they obviously formed the keystone for scientific Shroud research. The Shroud image base was tremendously improved both qualitatively and quantitatively when Giuseppe Enrie took his excellent photographs in 1931 and 1933. Copies of these 1931/33 images have been, and continue to be, used internationally for scientific analysis, and were the basis for the initial applications of digital processing to Shroud images (see Lorre (1977), Jackson (1977), Janney (1977)). Jumper (1978), Filas (1984) and Haralick {1983) also used copies of Enrie's photographs for their coins-on-the-eyes investigation.

The details of Judica Cordiglia's 1969 and 1973 photography are described in Judica Cordiglia (1976) and Curto (1976). It is not known by the author to what extent these images have been subjected to digital analysis.

The photography of the Shroud by the STURP team during the 1978 testing is described by Devan and Miller (1982), Miller and Pellicori (1981), Pellicori and Evans (1981) and Schwortz (1982). The magnification ratios (ratios of resolution on film to resolution on the Shroud) of the various STURP images are given in Table 1 of Devan and Hiller. From these values, the resolution on the Shroud of images scanned from these negatives can be calculated. To the author's knowledge only a few of the 1978 images have been digitized to date and processed as described in the following paragraphs.

To date there has been no digital data base compiled from existing images of the Shroud but the possibility of creating such a data base is currently being explored by Barrie Schwortz, Kevin Moran and the author.

How has Digital Image Processing been Utilized in the Investigation of the Shroud of Turin?

The intent of this chapter is to iterate "how" digital image processing techniques have been applied to images of the Shroud. Thus the following paragraphs are organized in terms of the techniques utilized, and Borne examples of the application of these techniques have been cited. No attempt is made herein to draw conclusions or summarize results from this body of work. It should be noted that the references and examples cited herein were drawn from the author's own library. Copies of, or references to, additional pertinent work are welcome.

Simple Contrast Enhancements

The initial digital image processing of images of the Shroud of Turin consisted of generating simple contrast enhancements of copies of Enrie's images. Simply put, contrast enhancement (also known in some cases as histogram equalization) consists of making the darker areas darker and the lighter areas lighter until the desired information can be seen more distinctly. Descriptions and examples of this process are given in Janney (1977), Lorre (1977), and Tamburelli (1981). Typical examples of the early products produced by Lorre are shown in Figures 1 and 2.

Insert Figure 1 about here

Insert Figure 2 about here

Similar enhancements have been applied to some of the 1978 STURP images and have been included in various papers, (eg., Avis, 1982), and Shroud exhibits; but to date there has been no comprehensive digital processing or publication of the 1978 Shroud images.

Application of Spatial and Spectral Filters

A process called filtering can be utilized for "smoothing" an image to 3Uppress certain types of noise, to reduce the gradation of intensity across an image, or to bring out details in certain frequency ranges. In this process, variations or gradations in intensity within a specified frequency band in the image are enhanced, while variations in intensity with frequencies outside the specified band are suppressed. This permits enhancement of desired information while suppressing data that may not be of interest. Descriptions and examples of these processes are given in Haralick (op. cit.), Janney (op. cit.), Jumper (1977), Lorre (op. cit.), Pickover (1988), and Tamburelli (1982).

Another analytical tool often used in image processing is called Fourier Transformation. Thie is a process whereby an image is broken down into the spatial frequency components of which the image is composed. The amplitudes and phases of these individual components can then be displayed for analysis and/or modification as desired. The modified components can then be reverse transformed to create a modified image. This technique is particularly useful when looking for dominant frequencies in the image, or for removing coherent noise.

Ae described in Lorre (op. cit.), this process was used in 1977 on Enrie's images to look for the presence of directionality in the Shroud images which might be indicative of manually applied brush strokes. See Lorre, Figures 6 through 9, for examples of image modification via Fourier Transformation.

Geometric Transformations

Geometric transformation consists of warping or "rubber-sheeting"' an image to conform geometrically to some desired form. Typical examples of this process are the three-dimensional representations of the Shroud as presented in Jackson (op.cit.) wherein image brightness has been used to represent a vertical dimension in order to produce a 3-D representation of the body of the man in the Shroud. (It should be noted that the VP-8 Analyzer which was used by Jackson and Jumper to produce these early 3-D representations is a hybrid analog/digital device (German, 1977)). DeSalvo (1983) also used a VP-8 to produce 3-D representations of the Volckringer patterns of plant material to illustrate how these images compare with those on the Shroud. Later 3-D representations, such as those of Tamburelli (1982, 1985), Avis (1982) and Jackson (1984, 1989), were accomplished using purely digital computers. In Jackson's later work digital computers were used to apply various mapping functions to compute body surfaces, to compensate for cloth drape, and to generate three-dimensional models of the Shroud figure.

Color Enhancements and False Color Representations

There is a subtle, but distinct, difference between color enhancements and pseudo-color/false color representations. In color enhancements, the differences between colors are exaggerated for emphasis, but the spectral relationship between the colored areas remains the same (i.e. areas which are shown in blue are not necessarily blue, but they are bluer than areas which are shown in yellow or red). In pseudo-color or false color representations, the colors do not necessarily bear any relationship to the actual colors of the scene; colors are assigned to maximize detection or discrimination between adjacent areas, and not to identify any specific color relationship between those areas. With false colored images, one must be careful not to misinterpret the meaning of the colors used.

An example of a color enhanced image is that shown on the front of the duet jacket of The Mysterious Shroud (Wilson and Miller, 1986). In this picture the body image ia reddish or rust colored because the actual body image on the Shroud is redder than the background cloth, which is shown in blue in that picture. The cloth appears in blue because, although the actual cloth is more the color of old ivory, it is "bluer" than anything else in the image. The color enhancements produced by Lorre (not documented) and others, permit definite discrimination between body image, scorch marks, blood stains, rust marks, etc. whereas this distinction is not readily apparent in black and white or color pictures such as those shown in National Geographic (Weaver, 1980).

An example of a pseudo-color image is Figure 8 in The Mysterious Shroud (Wilson & Miller, 1986). In this case the areas in the image which are of greater intensity are shown in red, regardless of whether they are from body image or bloodstain or crease in the cloth. Thus here is no correlation between the color in the picture and the colors of the Shroud, and is a pseudo-color or false color image.

Pickover (1988) has also used pseudo-color techniques to characterize certain features in the Shroud image.

Simulations

One of the areas of technology to which digital image processing is particularly well adapted is in the generation of simulations. A currently popular example of this is Virtual Reality in which the environment to which the operator is exposed is entirely generated by computer. The use of simulations in Shroud analysis to date has been much less esoteric. However, as the investigation of various mechanisms of image formation are pursued, it is believed that considerable use will be made of computer simulations of these mechanisms.

Typical examples of computer simulations utilized to date in Shroud analysis are the work of Jackson (1984, 1989), Ercoline (1982), Avis (1982) and others in investigating various 3-D representations of the cloth and the figure over which it was draped. As noted earlier, in these cases the intensity of the image on the cloth has been used to estimate a vertical dimension of the body figure, and this dimension ie used with the information in the two-dimensional image to construct three-dimensional representations of the body figure.

Avis (1982) describes a different type of simulation in which the pattern of illumination on the Shroud when it was photographed by STURP in 1978 was simulated and compensated for in order to permit reasonable color enhancements and quantitative color analyses. Tamburelli (1985) used a combination of filtering techniques to generate an image of the face in which the traces of wounds and blood have been largely removed.

Image Classification

One of the valuable image processing techniques used in remote sensing of the Earth is that of classification of areas based on common image attributes. In this technique, known areas of a given composition (fields of wheat or elm disease or copper deposits or whatever) are characterized based on their image attributes. It is then a simple matter for the computer to identify all other areas in the image having these same attributes.

This same technique may be applied to images of the Shroud in order to identify areas having the characteristics of blood stains, body image, scorch marks, water marks, etc. In this way the images may be decomposed into their various components and/or combination of components, and, as suggested by Kevin Moran (personal communication), might be used specifically in evaluating aging and deterioration of the Shroud. In order to accomplish this, however, it is essential that artifacts in the images introduced by illumination variation, exposure differences, camera transfer functions, etc. be properly compensated.

In addition, if the relationship between image intensity and cloth-body distance holds true over the entire Shroud, it may be possible, as suggested by Isabel Piczek (personal communication), to identify all places in the image where the cloth was in contact with, or close proximity to, the body. This, of course, would also require very accurately calibrated images.

Quantitative Comparison of Images

Another application to which image processing is particularly well suited is in the quantitative comparison of images. For instance, there is a systematic program currently underway at the National Archives to periodically compare images of the original Declaration of Independence, the U.S. Constitution and the Bill of Rights in order to evaluate possible deterioration of these documents with time.

Although, as noted previously, there exist detailed photographs of the Shroud taken over the past century, it remains to be determined whether any quantitative information about temporal changes in the Shroud can be obtained by comparison of these images. In his coins-on-the-eyes investigation Haralick (1983) has made comparisons of Enrie's 1931 images with those taken by STURP in 1978 and found differences in the way the cloth was stretched during the two periods. Thus, in order to perform any quantitative comparison of these time sequenced images, it will undoubtedly be necessary to geometrically transform them to the same spatial form. In fact, the degree of transformation required could provide information regarding the deformation of the cloth over that time period.

In future plans for conservation of the Shroud, some provision should be made for obtaining and comparing detailed time sequenced images.

Quantitative Color Analysis

What color is the body image on the Shroud? What color are the bloodstains? What color is the aged cloth? What colors are the scorch marks?

These questions cannot be answered quantitatively by visual examination of the photographs. The terms "sepia" or "rust" or "old ivory" are not quantitative specifications of color. The perception of color is very subjective; it is more a matter of brain interpretation than response of the eye. In fact, the perceived color of a scene can be changed merely by chanaina the level of illumination or the color of the background against which the scene is observed.

Although there have been "accurate" color photographs produced by Miller and others, and color enhancements generated, the only quantitative assessments of the actual spectral characteristics of the markings on the Shroud were made on small specific areas of the Shroud during the 1978 testing. Artom and Soardo (1983a) made detailed photometric and colorimetric measurements of discrete areas. Gilbert and Gilbert (1980) and Accetta and Baumgart (1980) made absolute ultraviolet, visible and infrared spectroreflectance measurements of selected stains and markings on the cloth. Pellicori (1980) made spectroreflectance measurements relative to the background cloth on a few specific markings. Unfortunately all of these measurements were made on relatively small, discrete and not necessarily coordinated areas. Although such quantification may not be particularly important for visual analysis, it can be very important in the evaluation of candidate mechanisms of image formation, and in the assessment of the rate of deterioration of the cloth and the images on it. Since there now exist quantitative standards by which colors can be specified and compared, such quantitative color evaluations and assessments should also be included in future plans for the Shroud.

Footnotes

[1]I wish to extend my thanks to Mr. Kevin Moran of the Estek Products division, the Kodak Corporation, for reading an early version of this manuscript and for his comments, and to Mr. Paul Maloney for supplying me with copies of publications in the original Italian which I did not have in my library.

[2]This item is known to me to be extant but I did not have access to it.

[3]These items are known to me to be extant but I did not have access to them.

[4]Dr. Silvio Curto says the year is 1934 and refers us, in note 22, to G. Enrie's work in La Santa Sindone nelle ricerche moderne. However in Enrie's article in the same publication. "Eaclusione di ogni ipoteai di inversione del colore nella formazione delle impronte delle S. Sindone", he makes clear that there were exhibitions of the Shroud only in 1931 and 1933 (1941, 1950, p. 103). Therefore. Curto's date, "1934", is in error. I am indebted to Mrs. Dorothy Crispino who confirmed this fact in a conversation with Paul Maloney.

[6]The Report of the Turin Commission on the Holy Shroud is an unpublished English translation of La S. Sindone·Ricerche e studi della Commissione di Esperti nominata dall'Arciyescoyo di Torino. Card Michele Pellearino. nel 1969. Supplemento Riyista Diocesana Torinese, Torino, Italia, 1976, 120 pp. The translation was by Maria Jepps, (Ed.), Fr. E. Doyle, O.F.M., Fr. Maurus Green, O.S.B., V. Ossola, and others. Page references in this chapter refer to the original Italian publication.

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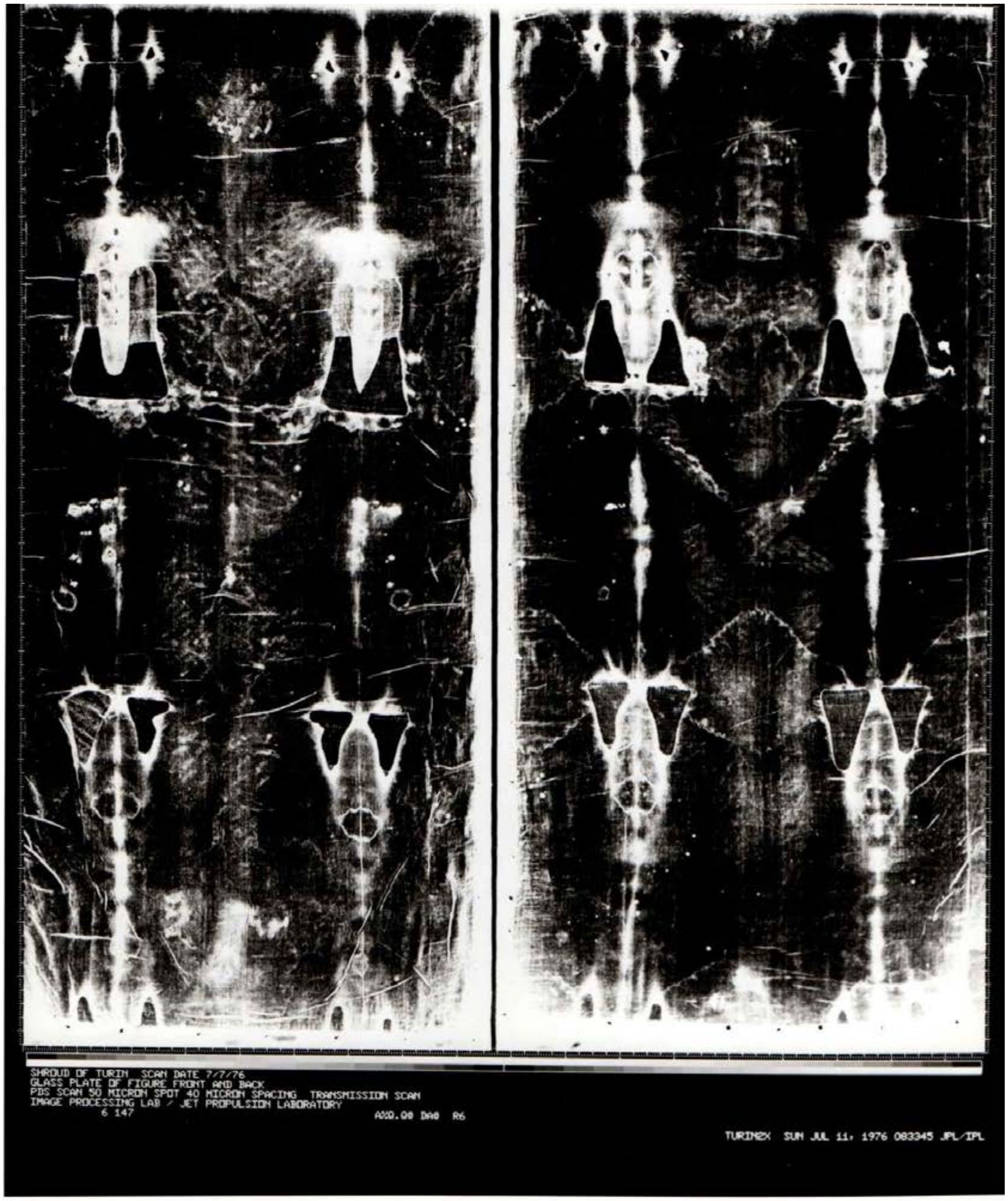
Captions

Figure 1. Fig. 1. Simple contrast enhancement of the Face of the Man on the Shroud of Turin. Processed by Jean Lorre at JPL in 1976 from a copy of one of Enrie's photographs. (Lorre, (1977).

Figure 2. Fig. 2. Simple contrast enhancements of the frontal and dorsal images of the body of the Man on the Shroud of Turin. Processed by Jean Lorre at JPL in 1976 from a copy of one of Enrie's photographs.
(Lorre, 1977).

Don Lynn DIGITAL ANALYSIS photographic and caption materials


SHROUD OF TURIN SCAN DATE 7/7/76
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