NUMERICAL ANALYSIS OF THE MUTUAL RADIATION EFFECTS OF COMPLEX SURFACES

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ABSTRACT
The Turin Shroud is a linen sheet that wrapped the corpse of a scourged, thorn-crowned crucified man that left a double body image not yet explainable by Science. In order to better understand the mechanism that could have generated the body image, a numerical simulation of the effects of radiation caused by complex surfaces such as face and hands on a wrapping cloth are studied in this paper. Based on the Lambert law, a mathematical model of radiation was built to simulate the effects of different kinds of radiation such as uniform emissivity, variable emissivity typical of non-metallic materials, and uni-directional emissivities in different directions. The best images are obtained when an uni-directional emissivity normal to the skin surface is considered.

1. INTRODUCTION

The Turin Shroud (TS) is a 4.4 m long and 1.1 m wide linen sheet, that wrapped the corpse of a scourged, thorn-crowned man who was stabbed in the side with a lance and crucified (Jumper 1984, Adler 1996). There are also many marks caused by blood, fire, water and folding impressed on the sheet that partially cancel the double body image (front and back) indelibly impressed (Figure 1). The wounds are what interest forensic pathologists most because they would be very difficult to produce.

The body image is extremely superficial but in some areas of the frontal image, such as those of the face and perhaps hands, it is superficial on both sides (Fanti et al. 2004). This means that, considering the thickness of the fabric where the image of the face is, there is a very superficial image on the top and one on the bottom, but nothing in the middle; the two images correspond in both shape and position.

The TS is believed by many to be the burial cloth in which Jesus Christ was wrapped before being placed in a tomb in Palestine about 2000 years ago. It is the most important relic of Christianity and has generated more controversy than any other religious relic.

The "Shroud of Christ" first appeared in Europe in 1353 at Lirey, France, under mysterious circumstances and with no documentation whatsoever. From the VII century A.D. many coins (gold solidus) in which the image of Christ was very similar to that of the TS appeared in the Byzantine empire. In 1203, a soldier camping outside Constantinople with the Crusaders who sacked the city the following year, noted that every Friday a church there exhibited the cloth in which it was said that Christ had been buried, with the figure of his body impressed on it. It is probable that this cloth and the TS are the same, especially since pollen typical of Turkey has been found on the TS (Frei 1978). It seems that the TS was among the spoils of the Crusades, together with many other relics brought back to Europe.

In 1532, a fire damaged the TS while it was conserved at Chambéry in France. The Chambéry nuns later restored the TS by sewing some patches of cloth on the back of it.

Scientific interest in the TS developed after 1898, when S. Pia, who photographed it, noticed that the negative image on the TS looked like a photographic positive. In 1931, G. Enrie photographed the TS at high resolution using an orthochromatic plate. In this photograph, the TS body image looks like a photographic negative, and its luminance levels can be related to the 3D image of a human body. The bloodstains are of human blood, transposed to the linen fabric by fibrinolysis (Adler 1996).

A probabilistic study (Fanti et al. 2000), analysing 100 statements formulated for and against the authenticity of the TS, shows that it is the burial sheet of Jesus Christ of Nazareth, with a probability of 100% and negligible uncertainty.

A scientific analysis of the TS in 1978 by the STURP (Shroud of TUrin Research Project) (Jackson 1984, Jumper et al. 1984, Adler 1996), concluded that the body image on the TS cannot be explained scientifically. One attempt at explanation states that the image formed as if it were caused by exposure to a short-lived but intense source of energy coming from the body enveloped in the TS itself.

Many hypotheses and experimental tests have been carried out on linen fabrics to explain the formation of the body image, both in favour of its authenticity, and vice versa. The following lists some examples.

- The body image is due to an energy source coming from the enveloped man, perhaps during the Resurrection: this source may be protonic, electronic, ultraviolet (UV) or anther type (Scheuermann 1983, Jackson 1984). Clearly, any scientist who makes such a statement leaves the domain of Science, at least partially, since a scientifically unexplainable phenomenon is presumed to exist;
- The image, which originated by direct contact of a body with the sheet, is due to a natural chemical reaction, perhaps similar to the effect of herbaria leaves (Volckringer 1991);
- The image is the result of the emanation of ammonia vapour (Vignon 1902) or the interaction of gases produced by the corpse with substances (saccharides) derived from retting of the linen (Rogers 2002);
- The image is a painting: many techniques have been proposed, but the best results were obtained using a modified carbon dust drawing technique (Craig & Bresee 1994).
- It was obtained from a warmed bas-relief (Pesce Delfino 2000).
- It was obtained by rubbing a bas-relief with pigments or acids (Nickell 1991).
- It was obtained by exposing linen in a darkened room using chemical agents available in the Middle Ages (Allen 1993).
- It is a natural phenomenon - a corona discharge - which occurred in the grave during an earthquake (Lattarulo 1998, De Liso 2002).

The hypothesis of a source of radiation from inside the enveloped body is the most convincing one, although some points must be still be demonstrated by experimental tests. All the other proposals do not conform to some peculiar characteristics of the body image discussed in the next chapter. Although good experimental results have been obtained - in the sense that the image, generally limited to the face, appears to be similar to that of the TS Man - until now no experimental tests have been able to reproduce all the qualities found in the image impressed on the cloth (Fanti et al. 2002). Jackson (1990) hypothesized a mechanism of image formation resulting from a burst of energy from inside the body, which had become mechanically transparent. He also predicted that an image would be found on the back surface of the TS, but only corresponding to the frontal image (because this part of the sheet went through the body due to the force of gravity, while the part of the sheet corresponding to the dorsal image remained stationary on the tombstone).

Many energy sources, such as thermal energy, are not able to reproduce the double superficiality of the TS image. A mechanism of formation which does satisfy this condition is electron emission (Scheuermann 1983), explaining the formation of a double superficial image from both theoretical (Lattarulo 1998) and experimental points of view (De Liso 2002).

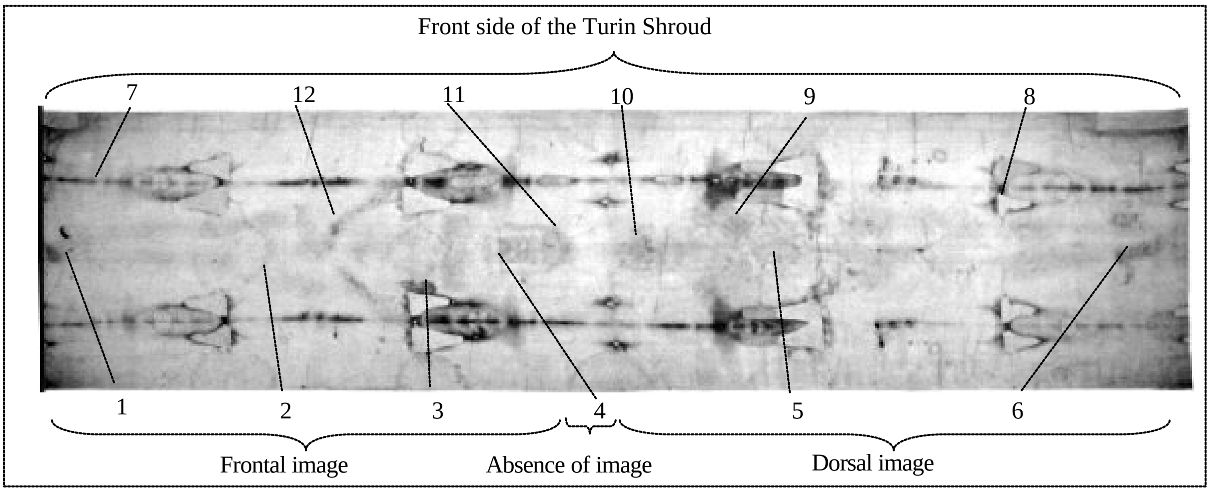


Figure 1: Body image and marks visible on TS: -1) Wound in right foot. -2) Marks of water before 1500. -3) Wound in side. -4) Folds in cloth. -5) Marks of scourging. -6) Wound in heel of right foot. -7) Carbonized lines in cloth, due to fire of 1532. -8) Mending done by Chambéry nuns after fire of 1532. -9) Bruises due to transport of patibulum. -10) Wounds on head, due to crown of thorns. -11) Wound on forehead. -12) Wound in left wrist (courtesy of Journal of Optics A: Pure and Applied Optics, volume 6, issue 6, 2004).

In 1988, the TS was radiocarbon-dated to 1260-1390 A.D. (Damon et al. 1989), but a great number of scientists believe that the sampling method and reliability of radiocarbon dating are not satisfactory because the cloth underwent many events (e.g. fires, repairs, water, exposure to candle smoke, visitors' breath). For example, some researchers have shown that the 1988 sample is not representative of the TS, because it has chemical and physical characteristics different from the main part of the cloth (Rogers 2002, 2005). In any case, it must be observed that neither science nor technology can currently reproduce all the characteristics of the body image. Therefore, the validity of applying a measurement method that depends on environmental conditions to an incompletely known object must be doubted.

In one statement, Walsh (1963) observed: "The Shroud of Turin is either the most awesome and instructive relic of Jesus Christ in existence ... or it is one of the most ingenious, most unbelievably clever, products of the human mind and hand on record. It is one or the other; there is no middle ground." From a scientific point of view, it would be very interesting to understand how a corpse could have generated such a peculiar image that even now cannot be reproduced in all its characteristics. From a religious point of view, it is important to understand what the TS is, because, if it is authentic, it witnessed the event of the burial and Resurrection of Jesus Christ.

Although the present paper does not answer this question, it does try to contribute to a thorough examination of the body image characteristics, with the aim of deciding what possible source of energy could have caused the image to form on the linen.

This paper focuses on the issue of the relatively high resolution of the body image because this parameter could be useful for the selection of image formation. In particular, many kinds of radiation can generate images, but it would be interesting to know some geometrical properties of the radiation in order to exclude other hypotheses. Perhaps the particular kind of radiation, e.g. light, thermic or electric, can be clarified from this characteristic.

In this study the effects of radiation of different kinds, emitted by complex surfaces such as face and hands, were numerically simulated in order to compare their effects on sheets posed around the emitting surfaces. Before presenting the numerical analysis, it is important to know something more about the particular features of the body image.

2. GENERAL FEATURES OF THE BODY IMAGE

The TS (Figure 1) has one frontal and one dorsal image of a nude man, separated by a space between the two images of the head. The images show an adult male, well-proportioned and muscular, with a beard, moustache and long hair, and are compatible with a man 175 ± 2 cm tall enveloped in a sheet (Basso et al. 2000). Due to rigor mortis, which began after his crucifixion, the TS Man was not completely supine but had his head tilted forwards, his knees slightly bent and his feet extended, as a result of being nailed to a cross.

The body image impressed on the TS has many peculiar physical and chemical characteristics which, even now, cannot be reproduced. Some of these (Jackson 1990, Moran et al. 2002) are:

-1) the body image has a resolution of 5.0±0.5mm (Fanti 2005); for example, the lips are clearly visible;

-2) the image penetrates into the cloth to a depth of no more than a few linen fibres;

-3) the luminance variation of both the frontal and dorsal images is related to the distance between the sheet and corpse, and is independent of implied body surface composition (e.g. skin, hair, etc.): 3D information may consequently be codified;

-4) side images between the frontal and dorsal images, i.e. the space between the two views of the head, are absent;

-5) from a chemical point of view, the image was caused by molecular changes in the sub-micrometer-thick coating of saccharides around image fibers on the cloth, i.e. a conjugated carbonyl structure, in a state of dehydration (Rogers 2002);

-6) the red stains are human blood, and were made on the cloth before the body image was produced, because no image exists under them;

-7) the body image is generally consistent with the vertical projection of a human body if a shroud is draped naturally over a body in evident rigor mortis lying horizontally in a position compatible with crucifixion (except the arms) (Fanti 2001);

-8) the maximum luminance level of the frontal image is about the same as that of the dorsal image, i.e. the dorsal image is not influenced by body weight, but the luminance level of the face is about 20% higher than that of the mean of the whole body;

-9) there are no signs of cementation among the fibres and no pigments on the body image;

-10) the frontal image is doubly superficial in the sense that the image of the head and perhaps the hands is superficial and visible on the two sides of the TS but there is no image in the middle of the fabric (Fanti et al. 2004);

-11) the image is, thermally and chemically stable;

-12) on the Shroud there are images even where surely there was no contact, e.g. between the nose and the cheek.

It is obviously not simple to experimentally obtain an image having all these peculiar characteristics.

In reference to points (1) and (7), the present paper simulates different types of radiation, i.e. uniform, variable and uni-directional, in order to show which of them can generate an image such as that of the TS.

3. THE RADIATION

Radiation can be defined as the flow of energy across open space via electromagnetic waves such as light or passage of heat from one object to another without warming the air space in between. In other words, it is the energy emitted in the form of waves (light) or particles (photons).

There are *corpuscular radiation* caused by mass particles such as α and β rays or particles generated by nuclear interactions, *electromagnetic radiation* generated by the movement of electric charges or by energetic transitions in molecules, atoms and nuclei, *nuclear radiation* caused by radioactive substances, and *acoustic radiation* composed by sounds, infra-sounds and ultra-sounds, which are elastic.

The electromagnetic radiation considered in this paper is subdivided into γ-rays, x-rays, UV, visible, IR, microwaves, radio-waves and long-radio-waves on the basis of their wavelength.

Based on the Lambert law, in the hypothesis of a black body and with reference to Figure 2, the following equations for Q, total radiative power exchanged may be written in reference to m couples of elemental surfaces (Bortoluzzi 2002):

$$Q = \sum_{i=1}^{m} dq_{i(1-2)} \qquad (1)$$

$$dq_{i(1-2)} = e_j \cdot dA_i \cos j_i \frac{dA_2 \cos j_2}{r^2} \qquad (2)$$

where e_j is the directional emissivity of a non-metallic material in the range from 0 to 80 °C and represented by the bold line on the left of the plot shown in Figure 3.

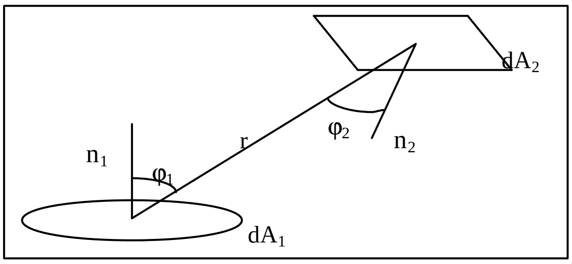


Figure 2: radiative exchanges between two black surface elements.

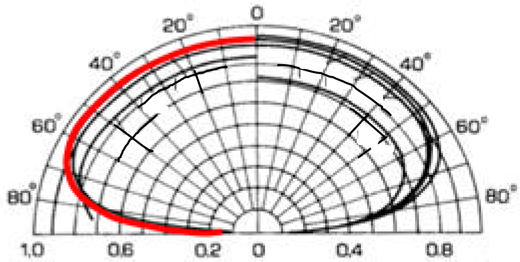


Figure 3: directional emissivity plot of non-metallic material.

4. NUMERICAL SIMULATION

Starting from the model described by eqs. (2) and (3), the effect of the radiation of complex surfaces, such as a hand or face, on a wrapping sheet was simulated using ad-hoc software.

This was qualitatively done to detect what kinds of images can be obtained by different types of radiation and which resulting image better fits that of the TS. The different types of radiation considered were (see Figure 4):

-a) perfectly diffusive radiation defined by the Lambert law (ε_ϕ=1),

-b) radiation ruled by the bold curve on the left of Figure 3,

-c) radiation only parallel to gravity acceleration,

-d) radiation only normal to the sheet ($\varepsilon_{j\,2=90°}$=1 $\varepsilon_{\phi\,2?90°}$=0);

-e) radiation only normal to the skin ($\varepsilon_{j\,1=90°}$=1 $\varepsilon_{\phi\,1?90°}$=0),

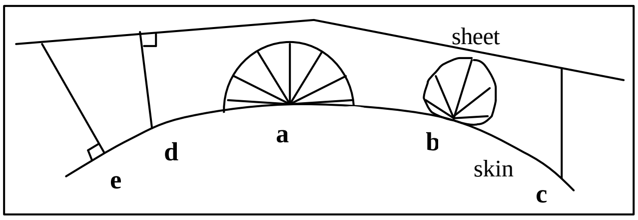


Figure 4: different kinds of radiative exchanges studied.

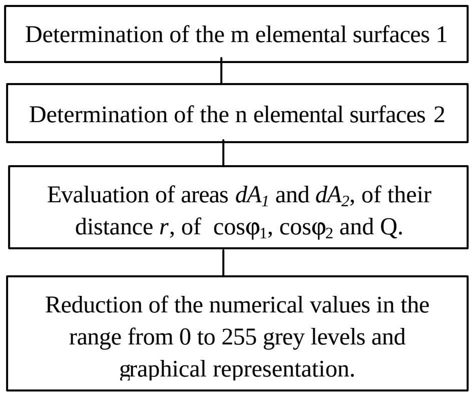


Figure 5: scheme of the procedure performed by the software developed to evaluate the radiation effects.

Both skin and cloth surfaces were subdivided into elemental surfaces and the radiation effect of the m elemental surfaces 1 of the skin were evaluated for each n (equal to 56x51 in the present case) elemental surfaces 2 of the cloth according with the scheme of Figure 5. Figures 6 and 7 represent the mesh used to simulate hand and face.

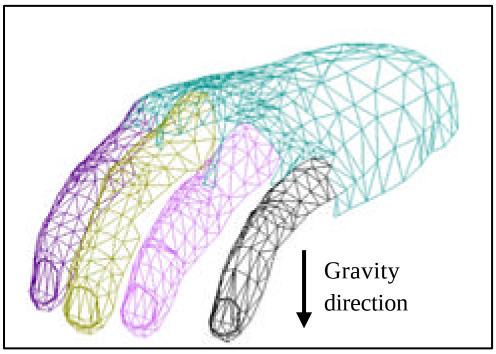


Figure 6: mesh of hand used to simulate radiation.

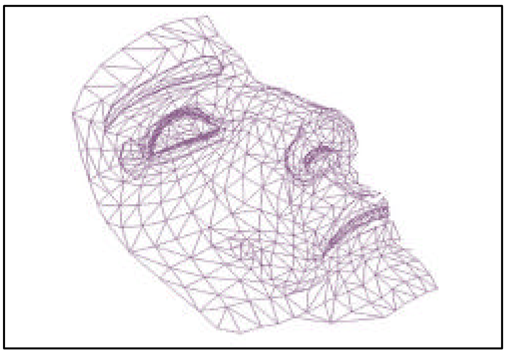


Figure 7: mesh of face used to simulate radiation.

5. QUALITATIVE RESULTS

Before using the software, it was tested by comparison with the results obtained by a certified software, Esarad® (which is less flexible), in the case of the two flat surfaces represented in Figure 8: Surface 1 radiates a perfectly diffusive radiation. Figure 9 shows the results in terms of radiation intensities seen by Surface 2. The results of the new software seem very similar, and perhaps more accurate.

In the case of the radiating mesh of the hand in Figure 6, the images shown in Figures 10, 11, 12 and 13 were obtained; in the case of the radiating mesh of the hand in Figure 7, the images shown in Figures 15, 16, 17 and 18 were obtained. To qualitatively compare the results of the simulations with the TS, Figures 14 and 19 respectively show the hand and the face of the TS.

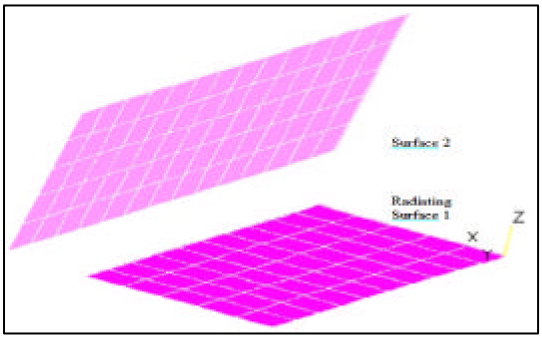


Figure 8: test case used to verify the software.

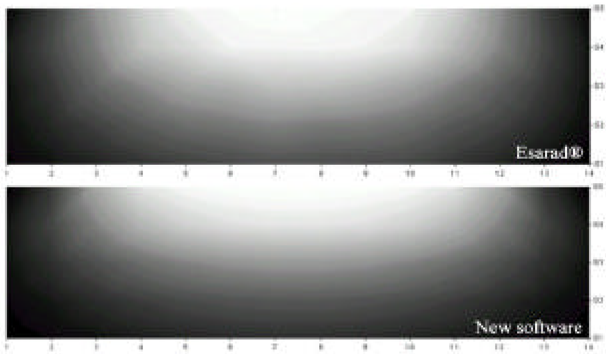


Figure 9: results of the test case: the new sw (on the bottom) appears more accurate than , Esarad® (on the top).

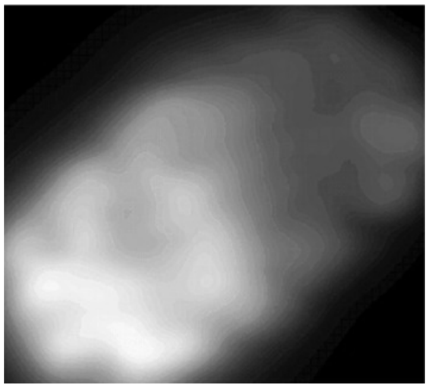


Figure 10: hand image resulting in the case of diffusivity ruled by the bold curve on the left of Figure 3.

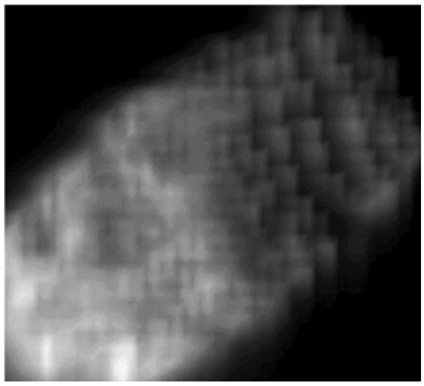


Figure 11: hand image resulting in the case of radiation only parallel to gravity acceleration.

The results for the hand are more significant than those for the face. If compared with the TS image, the best result is obtained with a radiation source that is uni-directional and normal to the skin surface.

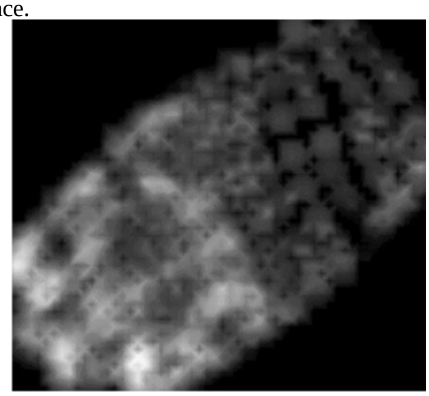


Figure 12: hand image resulting in the case of radiation only normal to the sheet.

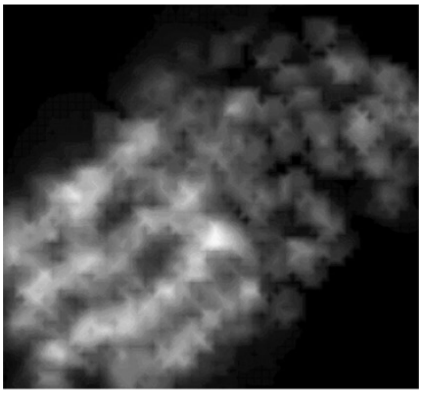


Figure 13: hand image resulting in the case of radiation only normal to the skin.

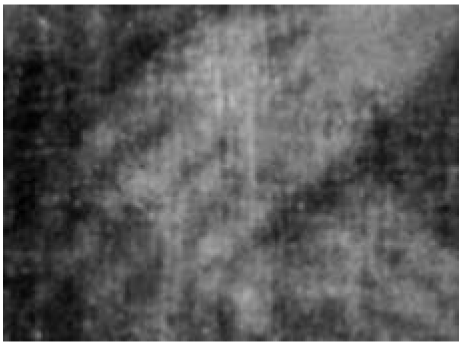
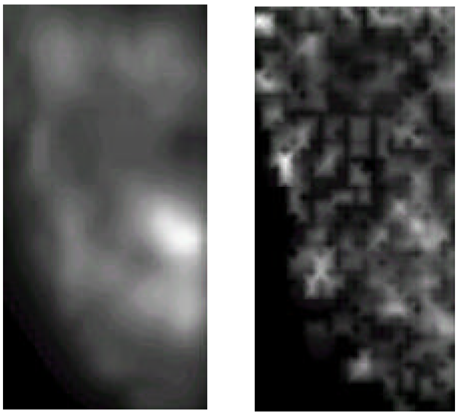
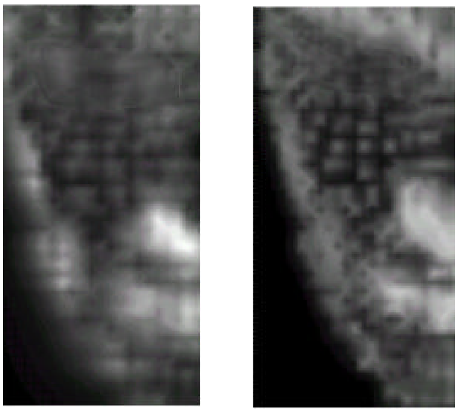


Figure 14: TS hand used for comparison.



Figures 15 (left) and 16 (right): head image resulting in the case of (15) radiation ruled by the bold curve on the left of Figure 3 and of (16) radiation only normal to the sheet.



Figures 17 (left) and 18 (right): head image resulting in the case (17) of radiation only parallel to the gravity acceleration and (18) radiation only normal to the skin.

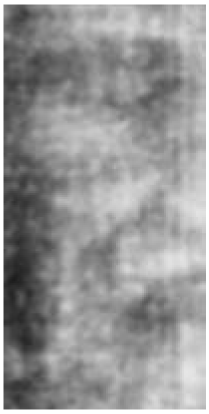


Figure 19: TS face used for comparison.

The effects of a gas diffusion mechanism are very similar to the case of radiation ruled by the bold curve on the left of Figure 3. From the results shown in Figures 10 and 15, it is clearly visible that a gas diffusion mechanism is not able to form a body image with a resolution comparable with that of the TS.

6. QUANTITATIVE RESULTS

The results relative to the hand can be qualitatively evaluated if the luminance profile of each image is compared. Figure 20 shows the luminance profile relative to TS hand in Figure 14 and the image of the hand obtained in Figure 13 in the case of radiation only normal to the skin.

The matching of each luminance profile of the hand images, obtained in Figures 10-13 with reference to the TS hand, was evaluated by means of the following equation:

$$R = \frac{\sum_j \left| F_j T_j \right|}{\sum_j F_j^2} \qquad (3)$$

where F_j and T_j are respectively the luminance values of the calculated hand and the TS hand. The closer the R values (shown in Table 1) are to unity, the closer the calculated luminance profiles are to the TS hands.

The best result (R=0.93) is reached in the case of radiation only normal to the skin; the worse result (R=2.28) is reached in the case of a radiation emitted in all the directions (similar to a gas diffusion hypothesis).

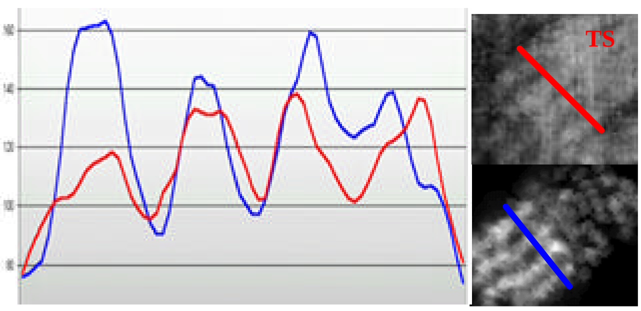


Figure 20: luminance profiles along the indicated lines, relative to the hand images in Figures 13 and 14.

Image type	R
Radiation ruled by the bold curve on the left of Figure 3	2.28
Radiation only parallel to the gravity acceleration	1.30
Radiation only normal to the sheet	1.69
Radiation only normal to the skin	0.93

Table 1: correlation values obtained for different resulting images of the hand when compared to the TS.

7. CONCLUSIONS

The Turin Shroud shows a body image that Science has still not been able to explain. In order to better understand the mechanism that could have generated the body image, a numerical simulation of the radiation effects caused by complex surfaces, such as a face and hands, on a wrapping cloth were studied. A computer software based on the Lambert law was developed to simulate the effects of different kinds of radiation, i.e. uniform, variable and uni-directional.

The images of the hand proved to be more like the TS hand than the images of the face like the TS face perhaps because of the low number of elements the numerical mesh was subdivided into.

The best images were obtained, with a correlation coefficient R=0.93 with reference to the TS hand, in the case of a uni-directional emissivity normal to the skin surface. This might lead one to think that the radiation that generated the TS image was higly directional and normal to the skin. This condition is satisfied by a corona discharge mechanism.

The worst result was obtained (R=2.28) when radiation is emitted in all the directions, such as in the case of a common light source. This result is comparable to the effects of a gas diffusion hypothesis, showing that it cannot be taken into consideration.

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