Study of a vision system for the colorimetric mapping of the Turin Shroud

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ABSTRACT

Two different vision systems employable for a future normal and high resolution colorimetric-mapping of the Turin Shroud are proposed. Once defined the requirements of the experimental apparatus, the resulting design is discussed.
Some procedural and numerical solutions are proposed to reduce the measurement uncertainty due to the principal influence quantities such as: temperature, thermoelectric noise, not uniform lighting, chromatic influence of the standard samples and geometrical distortion.
An example to reduce chromatic effects in an extreme case corresponding to the acquisition of the man face of the Turin Shroud is presented and discussed.

1) INTRODUCTION

Notwithstanding the several scientific studies carried out on the Turin Shroud (TS) we clarified different aspects, infact many problems still remain unsolved, the first of which regards the determination of the mechanism that caused the body image of the Man of the Shroud.
As for this, different hypotheses were made among which the effect of an energetic phenomenon bound to the Resurrection[1], the effect of aloe and myrrh that interacted with the sweat of the body wrapped in the cloth[2], the chemical effect through body-sheet contact analogous to that one notices in the herbaria[3], the singe[4], etc. Of all the hypotheses made, except the first one that is not easy to scientifically support because of problems of science-religion exceeding, one showed all the other ones unacceptable because they don't allow to completely obtain the particular features of the body image.
Therefore it is necessary to carry out a multidisciplinary study that tries to explain, at least partially, different aspects of the phenomenon till now unknown; it is foreseen, since 2000 a campaign of measurements on the TS, in collaboration among world-famous scientists, to try to throw light on some still unknown aspects.
To clarify different points it is necessary to have also a high definition mapping of the sheet, realized with innovating techniques. A proposal of colorimetric mapping with high spatial and chromatic resolution to be realized with artificial vision systems based on digital photocameras and colorimetric mask for the comparative analysis between standard sample colors and the TS image has already presented[5].

(*). For merely achademical purposes, the individual contribution of the single authors is specified like follows: M. De Cecco (40%) deviced the software for the elaboration of the images, elaborated the algorythms for the reduction of the interfereing effects and dealed with the experimental part with G. Fanti (60%) who developed the proposal presented in a previous work and formulated the method to reduce the effects of the disturbances in the images acquisition.

The proposal of high dimensional and chromatic resolution colorimetric mapping[5] has the purpose to: a) obtain, with various resolution levels, a TS data base for future studies; b) realize a digital colorimetry with a level of pixels useful for different applications, among which also a correlation between the mass of the human body and the possible radiation that would have caused the body image; c) make a digital colorimetry able to point out the temporal stability or the possible colorimetric degrade of the image; d) get a tridimensional reconstruction with high resolution of the whole impressed human body.
Differently from the traditional spectrophotocolorimeters that transform the spectral measures of image areas in the corresponding tristimulus values (RGB components of Red, Green and Blue), the proposed system allows (with a more limited chromatic resolution if one doesn't use narrow band filters) to acquire the tristimulus values not mediated on the whole area of acquisition, but corresponding to each point (picture element = pixel) of the acquired image.
If for instance one acquires a portion of the TS image with a sensor having 3000x2000 pixels, one will have 6.000.000 different colorimetric information, each in reference to the single area acquired by the pixel. It will be therefore possible to carry out comparative analyses among the different tristimulus values of the single points of the body image or of the blood imprints, etc. .
In this work the chromatic resolution of different digital systems with the purpose to optimize the system and the acquisition procedures is considered. The chromatic stability of the acquired image is a fundamental requirement, strongly dependent from the lighting conditions and from the "electric noise" of the acquisition and support system.
Here we deal more in detail with metrologic problems regarding the acquisition and the correction of the images in such a way as to reduce the uncertainty of measure both in the chromatic values and in those of the pixels superficial position of the obtained images.

2) PROPOSED COLORIMETRIC MAPPINGS

With reference to the previous work[5], it was foreseen the realization of four mappings of the TS with a different spatial resolution; in particular:

-2a) mapping with very high resolution (for future detailed analyses on particulars like coins and letters): such images, with dimensions of some centimeters, have pixels dimensions in the order of the micrometer.

-2b) mapping with high resolution through which one can obtain a mapping of 48 images in horizontal by 12 images in vertical with pixels dimension in the order of three hundredths of millimeter.

-2c) mapping with average resolution through which one can obtain a mapping of 8 images in horizontal by 3 images in vertical with pixels dimension in the order of two tenths of millimeter.

-2d) mapping with low resolution to obtain a complete picture constituted by only 4 images corresponding to the whole sheet, with pixels dimension in the order of the millimeter. Moreover such mapping is useful to check the average values of tristimulus colorimetry obtained through the mappings with a higher resolution.

Only mappings using reflected light coming from opportune illuminants that interest the visible light field (for instance like D_{65}) are here considered, but the analysis could be also extended to mappings in fluorescence excited by sources of ultraviolet light if one is interested in pointing out the blood imprints on the TS and the serum stains that surround the blood traces.

3) REQUIREMENTS OF THE EXPERIMENTAL APPARATUS AND ACQUISITION PROCEDURE

The acquiring system for the colorimetric mapping of the TS requires that one satisfies various requirements in such a way as to obtain a sufficiently stable system from a mechanical point of view, metrologically acceptable and sufficiently fast to allow the acquisition of many images in a limited time.
It is proposed a relative colorimetry because a comparison between the acquired values point by point (at a pixel level) of the TS and those mediated in a reference sample (previously calibrated) is considered.
One foresees for the moment to acquire the tristimulus values of the TS color through acquisition with color sensors of RGB (Red, Green, Blue) type; in the case one is interested in a colorimery with a more narrow band one can use B/W (Black and White) sensors with high sensibility combined with an opportune carrying filters wheel containing a twenty or more of narrow band filters.

3.1) Mechanical stability of the vision system.

The movable images acquisition system includes a photocamera or a videocamera with:

- spacer to maintain constant, during each kind of mapping, the distance between the sensor an the TS and therefore minimize the dimensional variation of the sight field,
- supporting mask of standard sample colors,
- surface of reference for the previous calibration of the system,
- supporting structure (that could be a tripod movable on rails fixed to the floor),
- lighting system, eventually including an integration sphere.

The supporting structure must be optimized from a:

- structural point of view to minimize possible vibrations of the support,
- mechanical point of view to maintain distances and previously defined inclinations during the whole mapping of the sheet in order to reduce possible geometrical distortions.

In relation to the kind of mapping realized (see §2), different acquisition systems are planned. A scheme of such systems is represented in picture 1.

3.2) Selection of the reference color samples

One foresees to realize a tristimulus colorimetric analysis of the TS relative to 3 reference samples characterized by as many mutually independent predominating colors. Obviously, in case one decides to carry out a chromatic analysis with a higher resolution through narrow band filters, the samples have to increase.
Such samples, opportunely calibrated through quality spectrophotometers, have to allow converting the colorimetric results of the TS in values conformable to CIELAB-76, CIELUV or CIELCH.
First of all one has to solve the metrologic problem of the standard samples selection that should satisfy the following four fundamental conditions; a standard sample can be chosen in an arbitrary way, but must be:

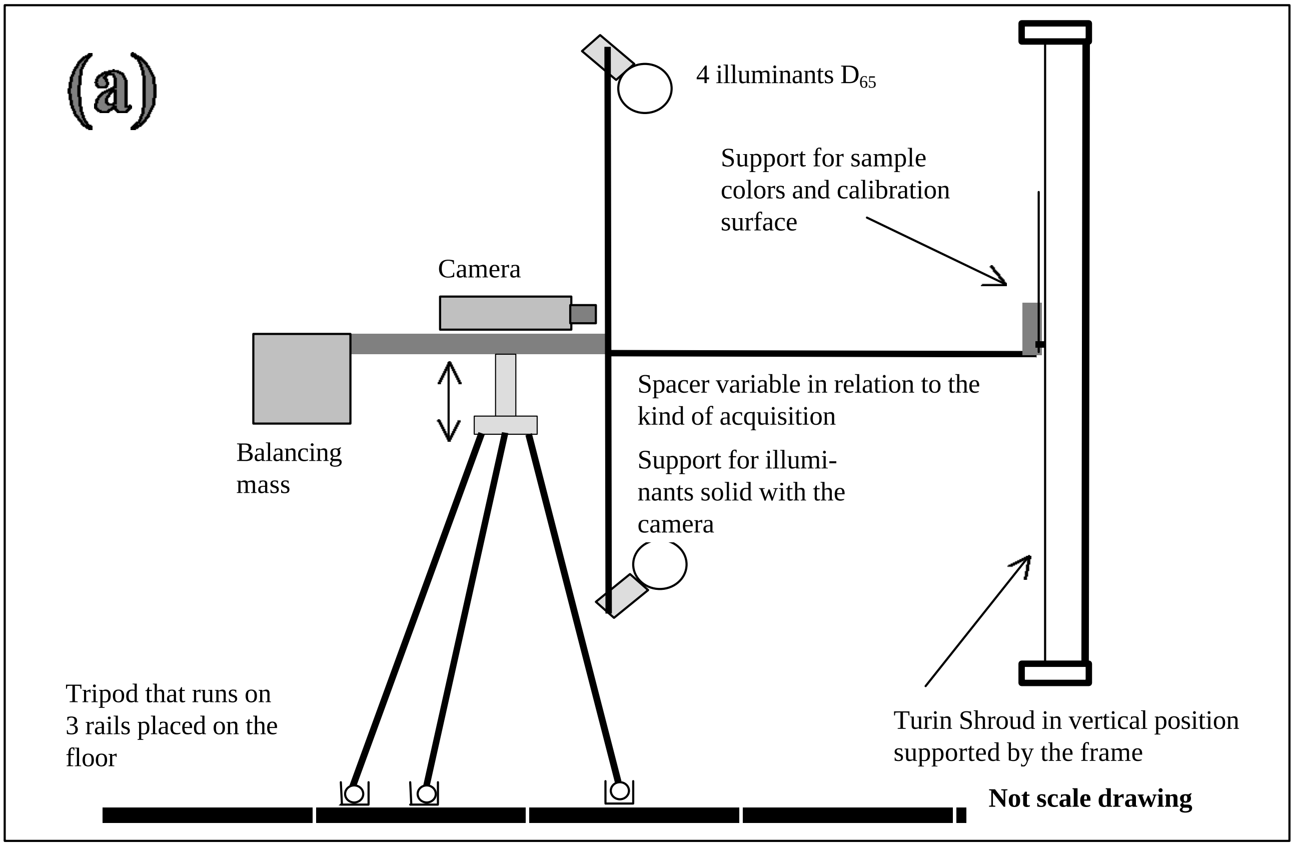
1) provided of minimum uncertainty;
2) reproducible in different equipped laboratories;
3) accessible in the sense that it can be used for measurements of reference;
4) invariable in the long run and after environmental variations, such as temperature, humidity, etc.

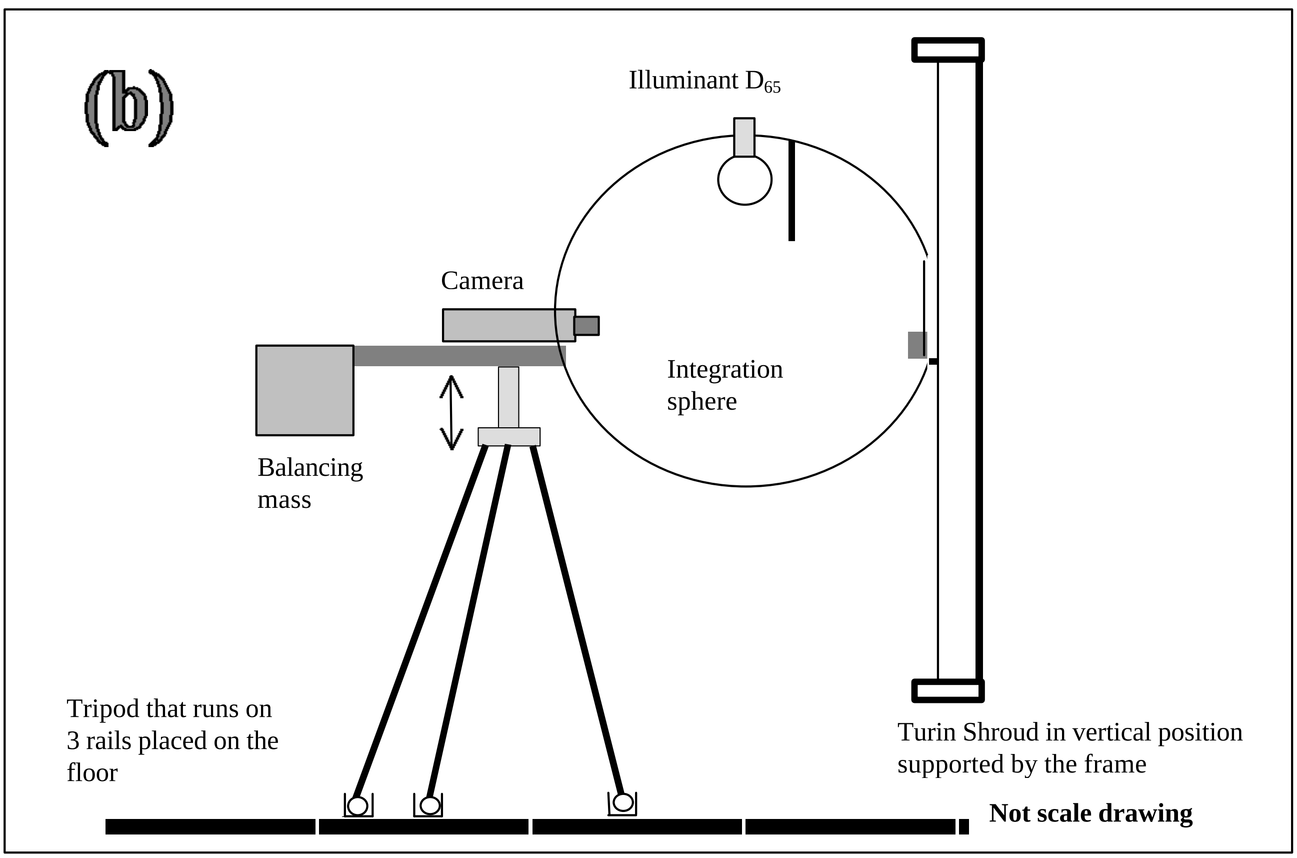
Since the plastic materials, constituting different standard samples don't completely satisfy the forth condition (for instance their colorimetric properties can vary after some tens of months if they are exposed to sunlight), one prefers to make reference, at least partially, to metallic samples.
One could chose for instance a golden sample and a platinum one pure at 999,9%.
Since the finish of the sample surface influences the acquisition, one can define an opaque surface obtained with a particular procedure of manufacture sufficiently detailed. Moreover one can define a method of a posteriori control, based for instance on the analysis of roughness.

3.3) Acquisition of high quality images

The system of digital acquisition must be chosen in such a way as to minimize the "thermoelectric noise" of the sensor.
The presence of noise in fact causes variations of the color levels, even of ±1%, that can increase the uncertainty of colorimetric valuation beyond the acceptable limits for the present analysis (see §4.2).
There are two possible solutions, that could be both adopted:

1) use of normal sensors CCD or CID in photocameras or in videocameras with high resolution in stable environmental conditions (temperature) and acquisition of a hundred of images of the same object; the image resulting from the average of such acquisitions would have a more reduced variance (in this case of a factor 10) in the hypothesis that the noise has only a casual origin;
2) use of sensors made cold down to cryogenic temperatures that are more expensive, but have better stability characteristics of the acquired signal.





Pict. 1: Scheme of the acquisition systems; in picture (a). It is showed the system foreseen for the mappings (2c, 2d); in picture (b). It is showed the system foreseen for the mappings (2a, 2b) with more limited sight fields that make useful integration spheres with acceptable dimensions.

3.4) Lighting system

One foresees to use different experimental apparatuses in relation to the kind of mapping to carry out on the TS: in particular a surface relatively reduced of the sample to acquire can allow the use of integration spheres with acceptable dimensions, able to provide a diffused lighting practically uniform; on the other hand, if one has to acquire images with dimensions in the order of the meter (such as those foreseen for the mapping (2d) with low resolution) the use of integration spheres would require spaces with almost prohibitive volumes and difficulties for the management of the acquisition procedure.
Therefore one foresees the use of an integration sphere with direct light illuminants D_{65} (illuminant with color temperature of 6500 K) for the very high and high resolution mappings (2a, 2b), while one prefers to use a quadruple illuminant D_{65} placed at 45° (like foreseen by CIE-Commission International d'Eclairage) for the mappings with average and low resolution(2c, 2d).

3.5) Procedure

It is important to define a detailed procedure to follow during all the colorimetric mappings.
Such procedure must moreover consider the fact that it could also be used within some decade or century if the possible degrade of the TS body image will be monitored.
In any case the procedure must be defined in such a way as to minimize all the possible sources of uncertainty, some of which will be discussed in the following paragraphs.
For instance one has to foresee the possibility to insert, on the surface of the image to acquire, opportune calibrated surfaces of reference (with uniform color and containing opportune grids of reference) in such a way as to have the necessary information to correct the more influential systematic effects such as for instance geometric distortions and not uniformity of lighting.

4. METHODOLOGIES FOR REDUCTION OF DISTURBANCE EFFECTS

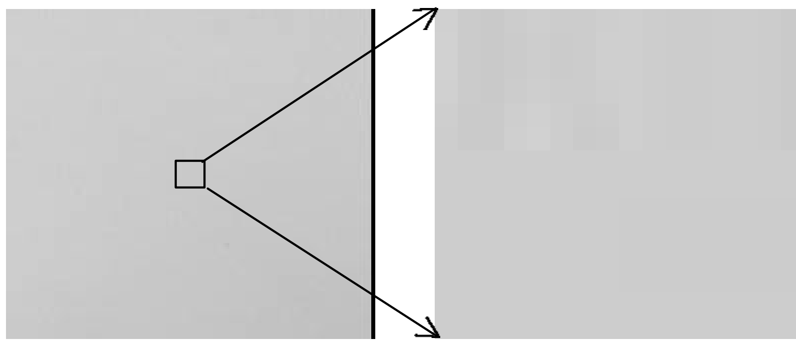
The colorimetric mapping system here proposed is subject to various sources of uncertainty due to the image acquisition system, to the lighting conditions and to the percentage of the different chromatic intensities present on the image itself.
In this paragraph both the nature and the compensation modalities of the main disturbance effects acting on the vision system are discussed; we refer back to another session the treatment of local effects, characteristic of the specific sensor, such as for instance the presence defective pixels and their effects on the contiguous pixels (cross-talk).

4.1 Temperature effects

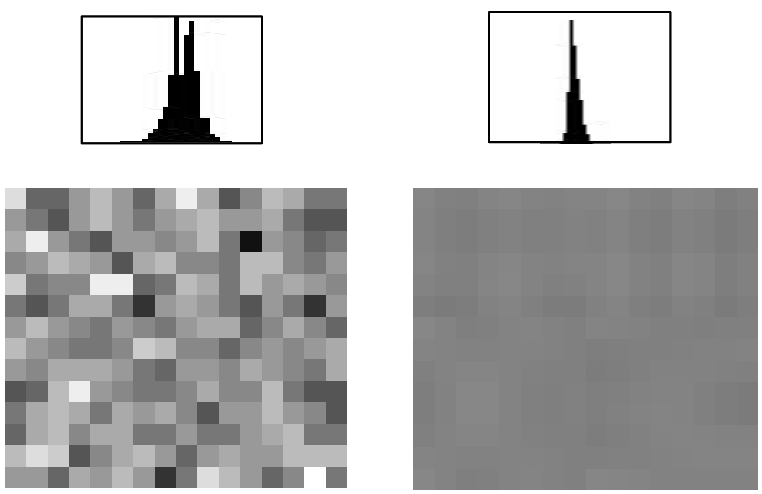
The temperature is a typical disturbance that in case of vision systems mainly influences the photocamera or the videocamera high-resolution sensor. One retains in fact negligible in this work the dimensional effect (translation and rotation) of the surface of reference respect to the acquiring system.
We don't retain that the temperature is a possible disturbance on the variation of the radiation emitted by the sample (TS) because the effect results negligible with the room temperature and in conditions of opportune outside lighting.
If one uses cooled sensors, the noise is certainly reduced, but in any case the different temperatures of work must be established in the procedure (for instance environment at 20±1 °C and sensor at -190±6 °C) in such a way as to reduce the systematic effects due to thermic excursions.

4.2 Effect of the thermoelectric noise

The CCD sensor of a videocamera is representable like a group of three matrixes of photodiodes, each one sensible to the three fundamental components: red, green and blue (RGB). Both the thermic noise and the electronic noise of luminous energy in tension conversion influence the primary elements.
The noise effect is not always visible at a microscopic level (if the spatial resolution of the human eye is less than that of the image, the human visual system mediates the different color tonalities making apparently uniform the acquired image). If one makes a zoom enhancing the dimensions of each pixel, see picture 2, such effect becomes evident (through the zoom one makes the eye resolution greater than that of the visual system).

(a)  (b)

Pict. 2 In the image (a), acquired with a resolution of 512x512 pixels, it is showed in B/W the only red component. The image (b) is enhanced 80 times in comparison with the image (a): in this way the thermoelectric noise becomes more evident.

(a)  (b)

Pict. 3: the picture (a) shows the result of the image 2b equalization. It is also showed (above) the color levels histogram in which it is evident a not repeatability effect. In picture (b) it is showed the corresponding image resulting from the average of ten acquisitions.

The prevalently casual nature of the present effect caused the definition of the following procedure of compensation: acquisition of a number N of images and average, for each single pixel, on levels corresponding to each image.

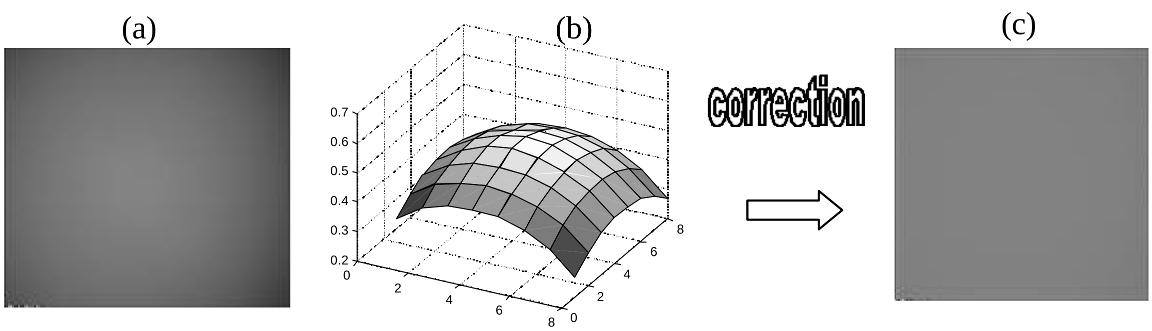
Defining S the intensity level variation in one of the three RGB bands, for each single image, one has a reduction of the average S_m, variation depending on the number N of acquisitions according to the relation:

$$S_m = \frac{S}{\sqrt{N}} \qquad (1)$$

To show the effect of the compensation through a number of N=10 images it was first made an equalization of the histograms to increase the contrast and make more visible the image effect of picture 2, therefore one made the averages. In picture 3a one shows the zooms of the equalized image 2a (with the relative histogram of the grey levels more over). In picture 3b it is showed the corresponding result of the averages.

4.3 Effect of the not uniform lighting

The not uniform lighting of the reference sample can cause variations in the luminance level of the single pixels not depending on the features of the object surface of which the mapping is realized, but on the orientation of the illuminants, on the spectral components of the incident light or on optics. Such effects tend systematically to vary the luminous intensity on the borders.
Once defined and placed the components of the vision system, the described effect can be considered of systematic nature. In the procedure of the TS colorimetric mapping therefore one foresaw a first phase of a reference sample image acquisition with uniform colorimetric level placed in the same points of the TS and oriented with the same angle. Through such image it is possible to compensate the systematic effects observed. The procedure consists in multiplying the levels of each pixel for an opportune correction factor determined through previous calibration.



Pict. 4 From left to right it is showed: (a) the original image of the uniform colorimetric rewference sample lighted in a not uniform way, (b) the tridimensional diagram of the function C(x,y) and (c) the result of the compensation realized on the image (a).

The images of picture 4 refer to a uniform sample. The image 4(a) presents a distribution of the red level remarkably more intense in the middle respect to the borders.
The tridimensional diagram of picture 4(b) shows an interpolation of the color levels acquired in picture 4(a) as bidimensional function I(x,y), where x and y are the positions of the pixels inside the image and I the corresponding pixels level.

If one wants to transfer the red level of the image (a) to that of the central pixel $I_u(x_c,y_c)$, one determines the compensating function C(x,y) through interpolation with polynomial or spline functions:

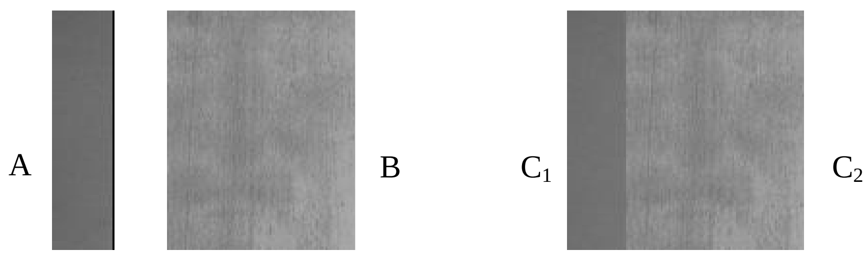
$$C(x,y)= I(x,y) / I_U(x_c,y_c) \qquad (2)$$

To compensate the image during the TS mapping it is sufficient to divide it, pixel by pixel, by the function C(x,y) obtained in the acquisition phase with an uniform sample. In picture 3(c) it is showed the effect of the compensation realized on the sample.

4.4 Mutual chromatic influence between the TS and the reference samples

It is known[6] that the average level of color acquired through CCD from reference samples of uniform color is not stable, but depends on the other objects present on the image (on their chromatic intensity and on the relative surface).

To study such effect in case of TS images acquisition, one acquired the three images of picture 5: the image (a) of a uniform red color sample in the videocamera whole field of sight, the image (b) of a reproduction of TS face alone, and (c) the image of both contemporaneously present in the field of sight.



Pict. 5 Acquisition of the only red reference sample (A), of the only TS reproduction (B) and acquisition of both images in the same field of sight (C_1 e C_2).

In table 1 one gives the averages of the color levels of the single pixels belonging to the four images portions showed in picture 5, valued for the three bands of color.

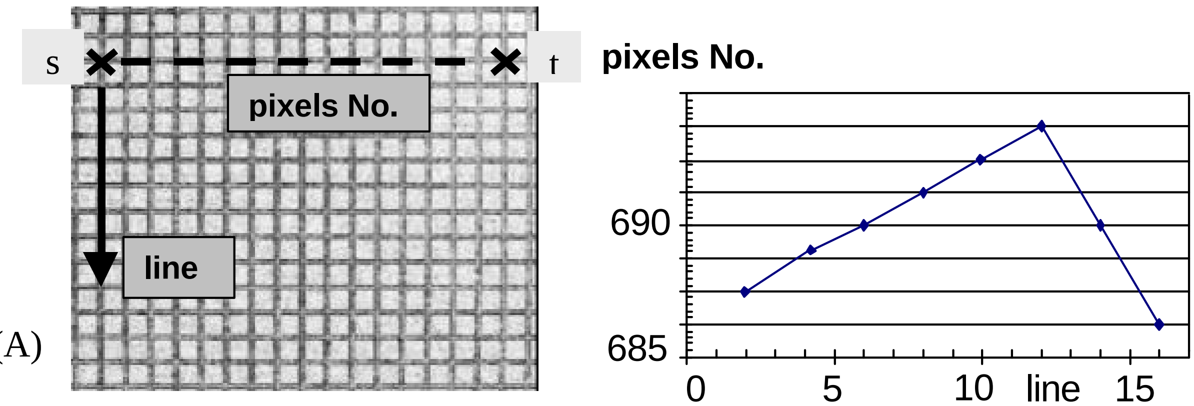
Image	Red	Green	Blue	Mean RGB value
A Red	107.6	44.9	53.8	68.2
B TS	139.4	108.3	93.0	116.3
C_1 Red (with TS)	112	47.2	56.0	71.3
C_2 TS (with Red)	138.9	108.3	92.1	115.7

Table 1 Results of the averages for the three images A, B, C_1 and C_2 of picture 5.

The averages variation is more remarkable for the reference sample and equivalent to about the 4.5%, but it is more reduced for the TS, equivalent to the 0.5 %. The relation of such variations is inversely proportional to the relation of the images areas themselves. The effect on the average grey level of an object A by an object B is the more remarkable the more the B area is large relatively to the A area.

4.5 Geometric distortion

The vision system optics, in combined action with the perspective effects, tends to deform the objects acquired in the field of sight.
In picture 6(a) it is showed the image of a grid on which it is possible to see the barrel effect. In picture 6(b) it is quantified such effect through a Cartesian diagram that has the number of pixels on the horizontal lines included between the points s and t in function of the ordinate.

(A)  (B)

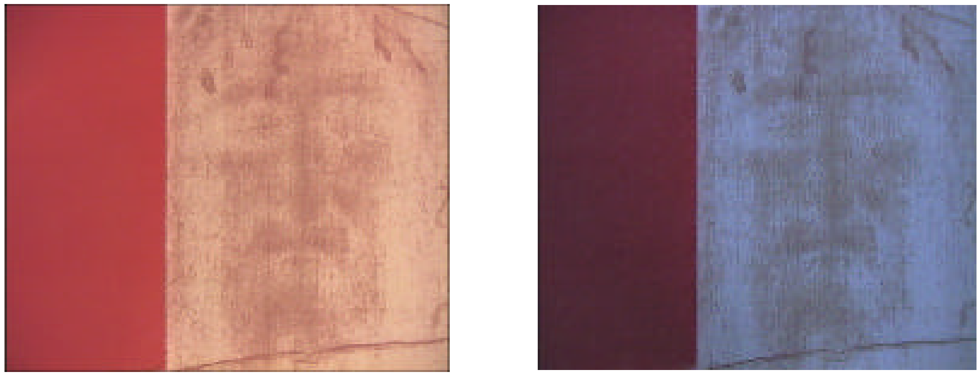
Picture 6(A): square mesh grid taken with a vision system.
Picture 6(B): Cartesian diagram of the pixels number included among the grid knots (showed with two crosses and the letters s and t) as a function of the considered line.

To compensate the deformation effect it is necessary to determine the correspondence between the grid pixels and the real position on the grid surface itself. Through the method of the similar transformations it is possible to correct the distortion a posteriori. Such procedure could be realized out of line during the system calibration phase.

5 RESULTS

As an applicative example it is considered the possibility to compensate the colorimetric levels of acquired images with illuminants having a spectral content completely different, on the basis of the knowledge of reference samples colorimetric levels (only one in this example).
To correct the image 7(B) characterized by a high blue dominant, we used the only red reference sample, acquired in the three RGB bands.
The strong blue component present in the image 7(B) was corrected determining three constants K_R, K_G, K_B relative to the three color bands through relation between the average value acquired from the sample in the image (B) and the value of reference that in this case is obtained from the average value of the image (A) sample. In reality the reference values will be relative to those defined for the primary sample.
The correction consists in dividing each pixel value in the three image components by the corresponding K_I factor.
The compensation in the extreme conditions 7(B) has a not completely satisfactory effect since the red reference sample is poor in the blue spectral components, therefore the uncertainty of the K_B coefficient is high.

The reference sample compensates in a more efficient way in the red field. In picture 9 one shows the two B/W images acquired in the only red component. The compensated image has the grey levels remarkably closer to the reference image with respect to the case of picture 8.

(A)  **(B)**

Pict. 7: in picture (A) it is showed the image acquired with a normal incandescence lamp. In picture (B) it is showed the image acquired with illuminants having predominant blue component.

Pict. 8 Correction of the image 7(B) through colorimetric comparison with a sole reference sample (red).

6 RESULTS DISCUSSION

In this work one didn't point out the metrologic answer of a particular sensor or of a particular acquisition system. The videocamera or the digital photocamera shall be defined during the next operative phase in which one will consider the time available for the TS acquisition and the liquid assets of the research, considering the possible innovative solutions offered by the market[7].
If the time available for the acquisition will allow it, it should be moreover opportune to add a traditional photocamera with sensible films to the vision system in such a way to maximize the quantity of information.

One pointed out how the different disturbance effects such as the temperature, the thermoelectric noise of the sensor, the not uniform lighting, the mutual chromatic influence between the reference samples and the geometric distortion can negatively influence the quality of the acquisitions obtained during the TS mappings with different resolution.

(A) **(B)** **(C)**

Pict. 9 In picture (A) it is showed the red component (R) of the image acquired with normal incandescence illuminants. In (B) it is showed the component R of the image acquired with illuminants in the blue. In picture (C) the image (B) acquired with illuminants in the blue was compensated through the average level found on the sample.

It is therefore of fundamental importance the optimization of the vision system, starting from the projectual phase, trying to minimize the uncertainties caused by the different effects pointed out.
Moreover it is necessary to define a detailed acquisition procedure of the images compatible with the time that will be assigned to the mapping operations, but that also allows to optimize the quality of the results through the use of opportune calibration plans (of uniform color to check the not uniformity of the chromatic intensity and with opportune grids for the geometric correction) to be inserted in the vision system before and after each mapping.
From the results obtained at the §5, it was pointed out the possibility to correct a posteriori the chromatic tristimulus values of images acquired also in extreme conditions.
However it resulted evident that the better correction can be obtained in the range of predominant colors of the reference sample (red in the example). For this reason it should be opportune to use at least three different chromatic samples characterized by three different predominant and mutually independent colors in the mask.
If one is interested in carrying out a colorimetric analysis with a higher chromatic resolution, one can use B/W sensors with high sensibility added to an opportune carrying filters wheel, solid for the acquisition system, containing an opportune number of narrow band filters.

CONCLUSIONS

Two different vision systems are proposed to be used for a possible future colorimetric mapping of the Turin Shroud with normal and high resolution.

The purposes and the execution modalities of the different mappings were discussed in a previous work[5]. In this study the requirements of such system are pointed out and the possible constructive solutions to adopt are discussed.

The main disturbance effects such as the temperature, the thermoelectric noise of the sensor, the not uniform lighting, the mutual chromatic influence among the samples and the geometric distortion are pointed out. For each of them, it is valued the correspondent measurement uncertainty and some solutions, both procedural and numerical, to reduce the measurement uncertainty caused by such disturbances are proposed.

It is necessary to optimize both the vision system, and the acquisition procedure, minimizing the various disturbance effects both environmental, by opportunely checking the environment of measurement, and electric-optical also foreseeing to carry out a posteriori corrections of the acquired images, by the comparisons with calibrated reference samples.

The applicative example of chromatic correction of an extreme acquisition case corresponding to a copy of the Man of the Turin Shroud face with illuminants having the prevalent blue component, shows the possibility of the chromatic correction through opportune numerical methods that must be verified before the effective mappings on the TS. The example points out the opportunity to use a mask with at least three chromatic reference samples independent among them.

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