Digital colorimetric analysis of the Turin Shroud

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Abstract. By using the data collected in previous colorimetric studies, a quantitative digital image with $\pm 4\%$ uncertainty relative to the color values, has been made. This goal was achieved by colors correction of a digitalized photograph performed through comparison with some published measurements in CIE XYZ color space. Starting from that image construction, a simply color measurement method was performed by using a common photographic software, and consequently allowing the construction of a colorimetric database of the main observable details of the Turin Shroud (TS). With this tools some analysis on TS colors were performed and interesting results were found: for example, it has been quantitatively demonstrated that the background cloth colors, gradually and continuously changes toward the typical shades of body image. From this work it has been also possible to distinguish colors differences between blood stains and the other stains which have proved to have of different origins.

1 Introduction

The Turin Shroud (TS) is believed by many to be the burial cloth of Jesus of Nazareth when he had been put in a tomb in Palestine about 2000 years ago. TS has generated considerable controversy but, beyond all the innumerable widely debated questions, it is a matter of fact that the TS exists as an archaeological object: thus it can be directly and objectively observed [1]. The results of the studies carried out on the TS can be analyzed by scientific methods.

The TS is a linen sheet about 4.4 m long and 1.1 m wide, in which the complete front and back body images of a man are impressed. The cloth is hand-made and each yarn (diameter about 0.25 mm) is composed of 70-200 linen fibers [2]. It has been shown by many scientists that the linen sheet enveloped the corpse of a man who had been scourged, crowned with thorns, crucified with nails, and stabbed by a lance in the side. Many other marks due to blood, fire, water and folding, are also impressed which have greatly damaged the double body image.

The TS has a front and a back image separated by a non-image zone of 0.18 m; the images show an adult male, nude, well proportioned and muscular, with beard, mustache and long hair.

Many hypotheses and experimental tests have been carried out on linen fabrics to explain the formation of the body image, in favor of both authenticity and the other way around [2]. Despite some macroscopic results with resemblance to the TS image which have often been achieved limited to the face, none of them has come close to reproduce all the TS image characteristics. In other words, even if at first sight, many image copies are similar to that of the TS, until now no experimental test has been able to reproduce all the characteristics found on the original.

From this brief description it is easy to understand how studies on the TS must be conducted wide-ranging in many fields of human knowledge, but given the current difficulty to directly perform analysis on the Relic, the studies are performed on materials collected by the STURP (Shroud of Turin Research Project) in 1978 and during other rare occasions.

Colorimetric analysis can be a way to solve some questions, but the works on this research field are few and too approximate because they have been performed on not calibrated image or didn't use a repeatable measurement method.

To perform colorimetric analysis a calibrated quantitative image of the TS was built and a standard measurements procedure has been determined on it [3,4]: with these tools many researchers will be able to perform colorimetric analysis on TS. This paper integrates with new content what has been already published [4].

2 Measurement instrument and procedure

2.1 The quantitative image

The aforementioned image was created starting from an image taken by photographer G. Durante in 2002. This picture with sizes of 6996×24197 pixel with a resolution of 300 dpi was used as the base image.

In 1978 researchers Soardo et al. performed color measurements on various details of the TS and expressed the results in CIE XYZ color space [5].

For calibrating the Durante's image, 18 points were chosen on it with a certain correspondence to the measurements points reported in Soardo's paper. By using a circular mask of a common photographic software with a diameter of 68 pixel (corresponding to the 13 mm of Soardo's colorimeter sampling spot) the statistical values of the single RGB color channel (values range 0 - 255) were read by means of the histogram function.

The color data, acquired by using Paint Shop™ Pro©, were converted from their sRGB color space representation to CIE XYZ space [6] and the CIE D55 type illuminant (used by G.Durante to realize his photographic work) was converted into CIE A type (used by Soardo et al. for colorimetric measurements) by using the Bradford matrix [7]. The acquired RGB values were converted by the application of the followings matrix operations (subscript A and D55 identify color values expressed in CIE type A and type D55 illuminant):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_A = [T_1] \cdot [T_2] \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{D55} = [T] \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{D55} \quad (1)$$

Where:

$$[T_1] = \begin{bmatrix} 1.1803 & 0.0969 & -0.1386 \\ 0.1334 & 0.9183 & -0.0499 \\ -0.0217 & 0.0327 & 0.3732 \end{bmatrix}; \quad [T_2] = \begin{bmatrix} 0.4125 & 0.3576 & 0.1804 \\ 0.2127 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9503 \end{bmatrix}; \quad [T] = \begin{bmatrix} 0.5049 & 0.4748 & 0.0882 \\ 0.2494 & 0.6985 & 0.0429 \\ 0.0052 & 0.0601 & 0.3531 \end{bmatrix}; \quad (2)$$

- [T1] is the Bradford matrix for illuminant conversion from CIE D55 to CIE type A;

- [T2] is the conversion matrix from sRGB to CIE XYZ color space;

- [T] is the transformation matrix, the resulting matrix product of [T1] and [T2].

The x, y, z chromatic coordinates (values range 0 -1) can be obtained by using eq.3:

$$x = \frac{X}{X+Y+Z}; \quad y = \frac{Y}{X+Y+Z}; \quad z = \frac{Z}{X+Y+Z}; \quad (3)$$

The acquired data were compared with the Soardo's measurements, finding that the mean differences were caused by an additive systematic effect. So additional constants δ_x , δ_y , δ_z were calculated by the difference between the arithmetic mean of the 18 converted RGB data acquired on Durante's photography and the corresponding arithmetic mean of the 18 reference measurements made by Soardo. The calculated constants δ_x , δ_y , δ_z have been added algebraically to the colorimetric values obtained by conversion of the RGB values to eliminate the additive systematic effect (Fig. 1 and 2).

Figure 1. X coordinate value before correction. It can be seen the additive systematic effect.

Figure 2. X coordinate value after correction with the additional constant.

After colors correction in CIE XYZ color space, the image was reconverted to sRGB standard by using the inverse color space transformation. The image built in such a manner turned out to be characterized by a calculated uncertainty on color values of $\pm 4\%$.

2.2 Measurement instrument and method

It was determined a measuring procedure starting from the method used for the quantitative image construction. As was done for the image calibration, the measurement instrument was "built" with masks and histogram functions of a common photographic software (Fig.3), through which were possible to read out the R, G, B channel value of a determinate area: the shape and the dimension of that area are fundamental elements, so it was important to investigate it.

The shape of the chosen selector was the circle, first of all for its wide availability in all the software's mask lists, then for its curved contours and because only center coordinates are needed for positioning it.

Figure 3. Histogram function of common photographic software. With this tool it can be read the average value of a single color channel in selected area

The size of the sampling area was determined by evaluating: the amount of pixels on which the program executes the average values of the individual channels, because it determines the sensitivity of the variations; the capability in balancing the tonal differences derived from the weft of the fabric. In fact the TS image is composed by an alternance of clear and dark fibers, so for balancing this effect the dimension of the measurement area must include equal number of fibers; the capability to test very small details.

The diameter of the circular mask was chosen equal to 12 pixels (in metric scale $d=2.3\text{ mm}$) (Fig.4).

Figure 4. Shape and size of the sampling area used in the image processing. Diameter dimension comparison: A) 12 pixel B) 20 pixel C) 40 pixel.

Robustness analysis was performed in order to verify the stability of the RGB measurements to variation of the shape and the dimension area of the measurement mask.

Original image was splitted in two parts (front and back image) with precise dimension. Then, for each part a coordinate system was defined (Fig. 5): (h, k) coordinates corresponding to the pixel position, so they can be detected directly from the software used for measurements.

The color measurement procedure can be summarized as follows: to open the histogram function, to choose a circular selection mask with 12 pixel diameter, to apply the mask on selected features, to read the RGB values by means values using the histogram function.

The measurement method can be applied to the Durante's photography by using a data-sheet for color conversion to obtain XYZ colors values and then to compare the results with the follow database.

Figure 5. The splitted image and the (h, k) coordinate system origin corner and axis orientation or for measurements.

3 Colorimetric analysis of details

3.1 Colorimetric measurements

Once calibrated the quantitative image, the following measurement has been performed on it:
 54 samples both on the front side and the dorsal of the body image (Fig. 6-7 and tab. 1-2);
 54 samples both on the front side and the dorsal of the bloodstains (Fig. 8-9 and tab. 3-4);
 54 samples both on the front side and the dorsal of the background cloth (Fig. 10-11 and tab. 5-6);
 30 samples, 16 on the front side and 14 on the dorsal side of the water stains areas (Fig. 12-13 and tab. 7-8);
 30 samples, 16 on the front side and 14 on the dorsal side of the burns areas (Fig. 12-13 and tab. 7-8).

For database and plots, chromatic coordinates in CIE XYZ color space were used because they are directly comparable with photometric measurements. So from the tables, for each measurement point reported in figures, the coordinates of the center of the sampling area (h, k), the chromatic coordinates obtained from RGB channel values conversion (x, y, z) and the dimensionless chromatic ratios used also for the plots construction (x/y, x/z, y/z) can be readed.

In table 9 the values range and their arithmetical average of the analyzed TS features were reported.

Figure 6. Measurement points on BODY IMAGE front.

Table 1. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 6 and related color values and dimensionless ratios.

BODY IMAGE chromatic values FRONT								
	h	k	x	y	z	x/y	x/z	y/z
A	3305	662	0.48	0.42	0.10	1.14	4.87	4.26
B	2877	805	0.48	0.42	0.10	1.14	4.72	4.16
C	3097	846	0.48	0.42	0.10	1.14	4.74	4.17
D	3472	945	0.49	0.42	0.09	1.15	5.23	4.56
E	3730	966	0.48	0.42	0.11	1.13	4.55	4.02
F	3280	1038	0.48	0.42	0.10	1.14	4.73	4.17
G	3122	1039	0.48	0.42	0.10	1.14	4.71	4.14
H	2806	1059	0.48	0.42	0.10	1.13	4.66	4.11
I	3449	1059	0.48	0.42	0.10	1.13	4.80	4.24
J	3057	1300	0.48	0.42	0.10	1.14	4.79	4.22
K	3286	1317	0.49	0.42	0.09	1.15	5.25	4.56
L	3504	1393	0.48	0.42	0.10	1.13	4.78	4.22
M	3119	1426	0.48	0.42	0.10	1.15	5.10	4.45
N	3714	1438	0.48	0.42	0.10	1.13	4.71	4.16
O	3088	1508	0.48	0.42	0.10	1.14	4.91	4.30
P	3088	1700	0.49	0.42	0.09	1.15	5.25	4.57
Q	3371	1711	0.49	0.42	0.09	1.15	5.18	4.51
R	3821	2482	0.48	0.42	0.10	1.13	4.69	4.14
S	2541	2539	0.48	0.42	0.10	1.13	4.75	4.19
T	2830	2824	0.48	0.42	0.10	1.13	4.58	4.05
U	3862	2845	0.48	0.42	0.10	1.13	4.73	4.17
V	2884	4121	0.48	0.42	0.10	1.13	4.70	4.17
W	4413	4188	0.48	0.42	0.10	1.13	4.60	4.06
X	2183	4224	0.48	0.42	0.10	1.14	4.68	4.11
Y	4513	4349	0.48	0.42	0.10	1.13	4.62	4.08
Z	2943	4367	0.48	0.42	0.10	1.14	4.93	4.32
AA	2257	4400	0.48	0.42	0.10	1.14	4.83	4.24
AB	4051	4438	0.48	0.42	0.10	1.13	4.64	4.11
AC	3582	4452	0.48	0.42	0.10	1.13	4.63	4.09
AD	4241	4460	0.48	0.42	0.10	1.13	4.64	4.11
AE	4009	4695	0.48	0.42	0.10	1.13	4.68	4.13
AF	2587	4751	0.48	0.42	0.10	1.14	4.74	4.18
AG	2906	5173	0.48	0.42	0.10	1.13	4.77	4.21
AH	3087	5233	0.48	0.42	0.10	1.14	4.89	4.28
AI	3274	5271	0.48	0.42	0.10	1.14	4.81	4.22
AJ	3220	5482	0.48	0.42	0.10	1.14	4.83	4.25
AK	2685	5662	0.48	0.42	0.10	1.14	4.74	4.18
AL	2978	5689	0.48	0.42	0.10	1.13	4.82	4.25
AM	2453	5692	0.48	0.42	0.10	1.14	4.78	4.20
AN	3484	5922	0.48	0.42	0.10	1.13	4.69	4.15
AO	2528	6016	0.48	0.42	0.10	1.13	4.67	4.11
AP	3447	6059	0.48	0.42	0.11	1.13	4.53	4.01
AQ	2744	6346	0.48	0.42	0.10	1.14	4.88	4.29
AR	3436	8545	0.48	0.42	0.10	1.13	4.79	4.22
AS	2734	8801	0.48	0.42	0.10	1.14	4.79	4.22
AT	3377	8950	0.48	0.42	0.10	1.13	4.74	4.19
AU	2889	9033	0.48	0.42	0.10	1.13	4.81	4.25
AV	2936	10122	0.48	0.42	0.11	1.13	4.55	4.02
AW	2992	10140	0.48	0.42	0.10	1.14	4.67	4.11
AX	3285	10207	0.48	0.42	0.10	1.13	4.62	4.08
AY	3274	10221	0.48	0.42	0.10	1.13	4.63	4.09
AZ	3148	10379	0.48	0.42	0.10	1.13	4.70	4.15

Figure 7. Measurement points on BODY IMAGE front.

Table 2. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 7 and related color values and dimensionless ratios.

BODY IMAGE chromatic values BACK								
	h	k	x	y	z	x/y	x/z	y/z
A	3997	783	0.48	0.42	0.10	1.14	4.92	4.30
B	3373	935	0.48	0.42	0.10	1.13	4.77	4.22
C	3543	1007	0.48	0.42	0.10	1.14	5.06	4.44
D	3277	1179	0.48	0.42	0.10	1.13	4.75	4.19
E	4040	1209	0.48	0.42	0.10	1.13	4.57	4.05
F	3548	1266	0.48	0.42	0.10	1.13	4.89	4.31
G	3745	1299	0.48	0.42	0.10	1.14	4.91	4.32
H	3633	1315	0.48	0.42	0.09	1.14	5.11	4.48
I	3762	1627	0.48	0.42	0.11	1.13	4.54	4.00
J	3581	1650	0.48	0.42	0.10	1.13	4.75	4.20
K	3824	2028	0.48	0.42	0.10	1.14	4.61	4.07
L	3515	2488	0.48	0.42	0.10	1.13	4.67	4.13
M	3202	2665	0.48	0.42	0.10	1.14	4.58	4.03
N	3853	3018	0.48	0.42	0.11	1.13	4.48	3.97
O	4339	3025	0.48	0.42	0.11	1.13	4.54	4.00
P	3560	3074	0.47	0.42	0.11	1.13	4.48	3.97
Q	3920	3372	0.47	0.42	0.11	1.13	4.42	3.91
R	3316	3902	0.47	0.42	0.11	1.13	4.41	3.91
S	4040	3921	0.48	0.42	0.11	1.13	4.49	3.97
T	3752	4190	0.47	0.42	0.11	1.13	4.44	3.93
U	3832	4698	0.48	0.42	0.11	1.13	4.48	3.97
V	3052	4909	0.47	0.42	0.11	1.13	4.46	3.97
W	4185	4987	0.48	0.42	0.10	1.13	4.63	4.08
X	3832	4999	0.48	0.42	0.10	1.13	4.62	4.08
Y	3186	5016	0.47	0.42	0.11	1.13	4.42	3.93
Z	3837	5589	0.47	0.42	0.11	1.13	4.46	3.95
AA	3580	6080	0.48	0.42	0.11	1.13	4.51	4.00
AB	4168	6198	0.48	0.42	0.11	1.13	4.51	4.00
AC	3522	6360	0.48	0.42	0.11	1.13	4.54	4.01
AD	4124	6693	0.47	0.42	0.11	1.13	4.43	3.93
AE	3946	8069	0.48	0.42	0.10	1.14	4.86	4.26
AF	3425	8325	0.48	0.42	0.10	1.12	4.56	4.06
AG	3423	8389	0.48	0.42	0.11	1.13	4.51	4.00
AH	4061	8552	0.48	0.42	0.10	1.13	4.63	4.09
AI	4249	8696	0.48	0.42	0.10	1.13	4.61	4.08
AJ	3967	8838	0.48	0.42	0.10	1.13	4.58	4.06
AK	3425	8979	0.48	0.42	0.11	1.13	4.50	3.99
AL	3410	9084	0.48	0.42	0.10	1.13	4.66	4.12
AM	3932	9084	0.48	0.42	0.11	1.13	4.53	4.01
AN	4067	9160	0.47	0.42	0.11	1.12	4.38	3.90
AO	4046	9205	0.48	0.42	0.11	1.13	4.53	4.00
AP	3527	9896	0.47	0.42	0.11	1.13	4.46	3.97
AQ	4096	10082	0.48	0.42	0.11	1.13	4.51	4.00
AR	3619	10328	0.48	0.42	0.11	1.13	4.53	4.01
AS	3993	10339	0.48	0.42	0.10	1.13	4.65	4.11
AT	3984	10477	0.47	0.42	0.11	1.13	4.48	3.98
AU	4319	10684	0.48	0.42	0.10	1.13	4.60	4.06
AV	3729	10719	0.48	0.42	0.11	1.13	4.55	4.03
AW	4072	10722	0.47	0.42	0.11	1.12	4.41	3.92
AX	3436	10768	0.47	0.42	0.11	1.13	4.48	3.97
AY	4174	10981	0.47	0.42	0.11	1.13	4.33	3.84
AZ	3505	11179	0.48	0.42	0.10	1.14	4.61	4.06

Figure 8. Measurement points on BLOOD front.

Table 3. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 8 and related color values and dimensionless ratios.

BLOOD chromatic values FRONT								
	h	k	x	y	z	x/y	x/z	y/z
A	2877	662	0.49	0.42	0.10	1.18	5.15	4.38
B	2954	683	0.49	0.42	0.09	1.18	5.20	4.43
C	2947	696	0.50	0.42	0.09	1.19	5.55	4.67
D	2953	696	0.50	0.42	0.09	1.19	5.49	4.62
E	3222	746	0.49	0.42	0.10	1.17	5.08	4.35
F	3564	803	0.49	0.42	0.10	1.17	5.17	4.41
G	3591	818	0.49	0.42	0.09	1.18	5.24	4.43
H	3195	846	0.49	0.42	0.09	1.18	5.44	4.61
I	3209	860	0.49	0.41	0.10	1.19	5.07	4.28
J	3222	869	0.49	0.42	0.09	1.18	5.39	4.58
K	3718	883	0.49	0.42	0.09	1.17	5.26	4.51
L	2975	900	0.49	0.42	0.09	1.18	5.31	4.52
M	2950	906	0.49	0.42	0.09	1.17	5.21	4.44
N	2980	924	0.49	0.42	0.09	1.18	5.29	4.50
O	3173	928	0.49	0.42	0.09	1.18	5.43	4.61
P	3163	945	0.49	0.42	0.09	1.18	5.51	4.68
Q	2839	2436	0.49	0.42	0.09	1.17	5.56	4.77
R	2671	2505	0.49	0.42	0.10	1.16	5.09	4.41
S	4092	3099	0.49	0.42	0.10	1.17	5.02	4.29
T	4002	3107	0.49	0.42	0.10	1.17	4.92	4.19
U	3970	3155	0.49	0.42	0.10	1.17	4.97	4.23
V	4045	3162	0.49	0.42	0.10	1.17	5.15	4.40
W	4045	3169	0.49	0.42	0.10	1.17	5.17	4.41
X	4054	3197	0.49	0.42	0.10	1.17	5.07	4.32
Y	2226	4161	0.49	0.42	0.10	1.17	5.14	4.38
Z	2230	4167	0.49	0.42	0.10	1.17	5.08	4.33
AA	2230	4168	0.49	0.42	0.10	1.17	5.01	4.28
AB	2227	4179	0.48	0.42	0.10	1.16	4.79	4.13
AC	2189	4267	0.48	0.42	0.10	1.16	4.85	4.17
AD	4332	4270	0.49	0.42	0.09	1.17	5.53	4.71
AE	4156	4411	0.49	0.42	0.10	1.17	5.04	4.33
AF	4091	4478	0.48	0.42	0.10	1.16	4.91	4.24
AG	4043	4510	0.49	0.42	0.10	1.17	5.02	4.29
AH	2514	4539	0.49	0.41	0.10	1.18	4.88	4.14
AI	2515	4539	0.49	0.42	0.10	1.17	4.86	4.14
AJ	2485	4572	0.49	0.42	0.10	1.17	4.87	4.19
AK	4042	4598	0.49	0.42	0.09	1.18	5.44	4.63
AL	3975	4613	0.49	0.42	0.10	1.16	4.97	4.27
AM	3966	4614	0.49	0.42	0.10	1.16	4.89	4.21
AN	3886	4701	0.49	0.42	0.10	1.17	5.08	4.36
AO	3781	4835	0.48	0.42	0.10	1.16	4.85	4.18
AP	3780	4895	0.49	0.42	0.09	1.16	5.19	4.46
AQ	2751	4972	0.49	0.42	0.10	1.18	5.07	4.29
AR	2910	5045	0.49	0.42	0.10	1.17	5.07	4.34
AS	2915	5049	0.49	0.42	0.10	1.16	4.99	4.29
AT	2797	5052	0.49	0.42	0.10	1.18	5.12	4.34
AU	2966	5101	0.48	0.42	0.10	1.16	4.81	4.14
AV	3526	10546	0.49	0.42	0.10	1.17	4.96	4.24
AW	3502	10655	0.49	0.42	0.10	1.17	4.82	4.14
AX	3292	10707	0.48	0.42	0.10	1.16	4.82	4.14
AY	3277	10727	0.48	0.42	0.10	1.17	4.77	4.09
AZ	3799	10862	0.49	0.42	0.10	1.17	4.91	4.20

Figure 9. Measurement points on BLOOD back.

Table 4. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 9 and related color values and dimensionless ratios.

BLOOD chromatic values BACK								
	h	k	x	y	z	x/y	x/z	y/z
A	3551	876	0.49	0.42	0.09	1.17	5.37	4.60
B	3665	1003	0.50	0.42	0.09	1.19	5.60	4.72
C	3821	1025	0.49	0.42	0.09	1.18	5.28	4.49
D	3937	1033	0.49	0.42	0.09	1.18	5.21	4.43
E	3819	1058	0.49	0.42	0.10	1.18	5.11	4.34
F	3820	1058	0.49	0.42	0.10	1.18	5.09	4.32
G	3762	1077	0.50	0.42	0.09	1.19	5.55	4.68
H	3747	1077	0.49	0.42	0.09	1.18	5.25	4.46
I	3476	1123	0.49	0.42	0.09	1.17	5.44	4.64
J	3720	1127	0.49	0.41	0.10	1.18	4.88	4.14
K	3727	1128	0.49	0.42	0.10	1.17	4.97	4.23
L	3875	1131	0.49	0.42	0.09	1.18	5.31	4.49
M	3522	1162	0.49	0.42	0.10	1.18	5.02	4.25
N	3710	1232	0.49	0.42	0.10	1.17	5.16	4.40
O	4155	2641	0.49	0.42	0.09	1.17	5.24	4.49
P	3519	2693	0.50	0.42	0.09	1.19	5.60	4.73
Q	4171	2848	0.49	0.42	0.09	1.18	5.47	4.65
R	3395	2928	0.49	0.42	0.09	1.17	5.61	4.78
S	3336	3337	0.49	0.42	0.09	1.17	5.70	4.88
T	3940	4306	0.50	0.42	0.09	1.19	5.38	4.51
U	3940	4311	0.49	0.42	0.09	1.19	5.41	4.55
V	4118	4336	0.49	0.42	0.09	1.18	5.53	4.70
W	3321	4386	0.49	0.42	0.09	1.17	5.39	4.62
X	3484	4419	0.49	0.42	0.09	1.17	5.44	4.66
Y	3432	4450	0.49	0.42	0.10	1.16	4.89	4.21
Z	4059	4453	0.49	0.42	0.09	1.17	5.25	4.47
AA	3647	4481	0.49	0.42	0.09	1.17	5.18	4.42
AB	3662	4486	0.49	0.42	0.09	1.18	5.53	4.70
AC	3107	4701	0.49	0.42	0.09	1.17	5.28	4.52
AD	3336	7537	0.49	0.42	0.09	1.17	5.58	4.76
AE	3182	8386	0.49	0.42	0.09	1.16	5.19	4.49
AF	3460	8427	0.49	0.42	0.10	1.15	5.03	4.36
AG	4176	8484	0.49	0.42	0.10	1.16	5.00	4.32
AH	4187	8486	0.49	0.42	0.09	1.16	5.25	4.53
AI	4163	8563	0.49	0.42	0.09	1.16	5.53	4.75
AJ	4207	10337	0.49	0.42	0.10	1.17	5.01	4.30
AK	4191	10345	0.49	0.42	0.10	1.16	4.97	4.29
AL	3487	10391	0.49	0.42	0.10	1.17	5.08	4.34
AM	4309	10391	0.49	0.42	0.10	1.17	5.10	4.36
AN	4272	10402	0.49	0.42	0.10	1.17	5.00	4.27
AO	3487	10421	0.49	0.42	0.09	1.18	5.23	4.44
AP	3434	10469	0.49	0.42	0.10	1.17	4.88	4.17
AQ	4275	10523	0.49	0.42	0.10	1.17	4.97	4.27
AR	4297	10567	0.48	0.42	0.10	1.16	4.88	4.20
AS	2926	10570	0.49	0.42	0.09	1.18	5.44	4.60
AT	3459	10600	0.49	0.42	0.10	1.17	4.91	4.22
AU	3052	10625	0.49	0.42	0.09	1.17	5.19	4.42
AV	3620	10965	0.49	0.41	0.10	1.19	5.10	4.30
AW	3623	10971	0.49	0.42	0.09	1.18	5.21	4.41
AX	3595	11009	0.49	0.42	0.10	1.17	4.92	4.23
AY	3508	11048	0.49	0.42	0.10	1.17	5.07	4.33
AZ	3506	11055	0.49	0.42	0.10	1.17	4.94	4.23

Figure 10. *Measurement points on BACKGROUND front.*

Table 5. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 10 and related color values and dimensionless ratios.

BACKGROUND chromatic values FRONT								
	h	k	x	y	z	x/y	x/z	y/z
A	1539	257	0.47	0.42	0.11	1.13	4.21	3.74
B	3910	466	0.47	0.42	0.11	1.12	4.17	3.73
C	4329	496	0.47	0.42	0.11	1.12	4.30	3.83
D	2293	600	0.47	0.42	0.11	1.12	4.11	3.66
E	1455	614	0.47	0.42	0.11	1.13	4.22	3.74
F	2551	629	0.47	0.42	0.11	1.13	4.37	3.88
G	2452	692	0.47	0.42	0.11	1.12	4.13	3.68
H	4068	706	0.47	0.42	0.11	1.12	4.22	3.77
I	2479	757	0.47	0.42	0.11	1.12	4.16	3.71
J	2218	789	0.47	0.42	0.11	1.12	4.18	3.72
K	2705	810	0.47	0.42	0.11	1.13	4.31	3.83
L	4157	924	0.47	0.42	0.11	1.12	4.27	3.82
M	2379	1163	0.47	0.42	0.11	1.12	4.27	3.80
N	3927	1190	0.47	0.42	0.11	1.12	4.23	3.78
O	4147	1535	0.47	0.42	0.11	1.13	4.40	3.91
P	2550	1763	0.48	0.42	0.11	1.13	4.45	3.94
Q	2142	1874	0.47	0.42	0.11	1.13	4.40	3.91
R	5448	1967	0.47	0.42	0.11	1.13	4.44	3.93
S	5685	2295	0.47	0.42	0.11	1.12	4.27	3.81
T	1006	2298	0.47	0.42	0.11	1.12	4.14	3.69
U	933	2449	0.47	0.42	0.11	1.12	4.26	3.79
V	5641	2557	0.47	0.42	0.11	1.13	4.46	3.96
W	5720	3520	0.47	0.42	0.11	1.12	4.18	3.73
X	1239	3906	0.47	0.42	0.11	1.13	4.28	3.81
Y	5441	4413	0.47	0.42	0.11	1.12	4.40	3.91
Z	5093	4517	0.47	0.42	0.11	1.12	4.23	3.78
AA	1378	4582	0.47	0.42	0.11	1.12	4.23	3.77
AB	5284	4600	0.47	0.42	0.11	1.12	4.21	3.77
AC	1438	4603	0.47	0.42	0.11	1.12	4.10	3.65
AD	5231	5726	0.47	0.42	0.11	1.12	4.22	3.76
AE	1127	5757	0.47	0.42	0.11	1.13	4.43	3.93
AF	1282	6277	0.48	0.42	0.11	1.13	4.47	3.95
AG	5138	6398	0.47	0.42	0.11	1.12	4.37	3.90
AH	5480	8927	0.48	0.42	0.10	1.13	4.55	4.04
AI	5515	9333	0.48	0.42	0.10	1.13	4.55	4.04
AJ	1494	9373	0.47	0.42	0.11	1.12	4.25	3.80
AK	1001	9621	0.47	0.42	0.11	1.13	4.39	3.89
AL	1151	9667	0.47	0.42	0.11	1.13	4.42	3.92
AM	2283	9721	0.47	0.42	0.11	1.13	4.35	3.86
AN	3905	9755	0.47	0.42	0.11	1.12	4.25	3.79
AO	5325	9801	0.47	0.42	0.11	1.12	4.42	3.94
AP	2115	9875	0.48	0.42	0.11	1.13	4.53	4.01
AQ	5613	10137	0.48	0.42	0.10	1.13	4.56	4.03
AR	5048	10156	0.48	0.42	0.11	1.13	4.52	4.01
AS	3725	10157	0.47	0.42	0.11	1.12	4.28	3.81
AT	2280	10198	0.48	0.42	0.11	1.13	4.47	3.95
AU	1130	10234	0.48	0.42	0.11	1.13	4.49	3.98
AV	5391	10294	0.47	0.42	0.11	1.12	4.32	3.85
AW	1374	10372	0.48	0.42	0.10	1.14	4.86	4.26
AX	4971	10401	0.48	0.42	0.10	1.14	4.76	4.19
AY	2699	10991	0.48	0.42	0.10	1.15	5.02	4.37
AZ	5993	10991	0.47	0.42	0.11	1.12	4.26	3.80

Figure 11. *Measurement points on BACKGROUND back.*

Table 6. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 11 and related color values and dimensionless ratios.

BACKGROUND chromatic values BACK								
	h	k	x	y	z	x/y	x/z	y/z
A	4320	500	0.48	0.42	0.11	1.13	4.53	4.00
B	2840	630	0.47	0.42	0.11	1.12	4.24	3.79
C	2415	639	0.48	0.42	0.11	1.13	4.51	4.00
D	2957	804	0.47	0.42	0.11	1.13	4.51	4.00
E	4520	812	0.47	0.42	0.11	1.13	4.40	3.89
F	2967	924	0.47	0.42	0.11	1.12	4.26	3.80
G	4494	951	0.47	0.42	0.11	1.12	4.39	3.91
H	4765	1111	0.47	0.42	0.11	1.13	4.33	3.84
I	1263	1419	0.47	0.42	0.11	1.12	4.39	3.92
J	1743	1441	0.47	0.42	0.11	1.12	4.21	3.76
K	5582	1443	0.47	0.42	0.11	1.12	4.17	3.72
L	5930	1954	0.47	0.42	0.11	1.12	4.15	3.70
M	5759	2147	0.47	0.42	0.11	1.13	4.28	3.80
N	1095	2174	0.48	0.42	0.10	1.13	4.55	4.04
O	931	2395	0.48	0.42	0.10	1.13	4.57	4.04
P	5961	2927	0.47	0.42	0.11	1.13	4.44	3.94
Q	1209	2989	0.47	0.42	0.11	1.12	4.34	3.86
R	1352	2996	0.47	0.42	0.11	1.12	4.10	3.66
S	1566	3402	0.47	0.42	0.11	1.12	4.24	3.78
T	1094	4650	0.47	0.42	0.11	1.12	4.29	3.82
U	1600	4883	0.47	0.42	0.11	1.12	4.19	3.73
V	5542	5079	0.47	0.42	0.11	1.13	4.24	3.77
W	5316	5437	0.47	0.42	0.11	1.13	4.33	3.84
X	5801	5572	0.47	0.42	0.11	1.13	4.38	3.88
Y	1555	6257	0.47	0.42	0.12	1.12	4.08	3.64
Z	5269	6490	0.47	0.42	0.11	1.12	4.15	3.71
AA	1993	6586	0.47	0.42	0.11	1.12	4.22	3.77
AB	4763	6738	0.47	0.42	0.11	1.12	4.22	3.76
AC	1870	7112	0.47	0.42	0.11	1.12	4.29	3.83
AD	4767	7134	0.47	0.42	0.11	1.12	4.15	3.70
AE	5371	7221	0.47	0.42	0.11	1.12	4.12	3.68
AF	1870	7518	0.47	0.42	0.11	1.12	4.18	3.73
AG	5121	7574	0.47	0.42	0.12	1.12	4.05	3.61
AH	2030	7594	0.47	0.42	0.11	1.12	4.29	3.82
AI	1394	8765	0.47	0.42	0.11	1.13	4.28	3.80
AJ	2612	8885	0.47	0.42	0.11	1.12	4.23	3.77
AK	2570	9441	0.47	0.42	0.11	1.12	4.25	3.79
AL	5572	9645	0.47	0.42	0.11	1.12	4.15	3.69
AM	5473	9774	0.47	0.42	0.11	1.12	4.11	3.67
AN	5330	10381	0.47	0.42	0.11	1.13	4.25	3.77
AO	5319	10559	0.47	0.42	0.11	1.13	4.22	3.75
AP	1463	10703	0.47	0.42	0.11	1.12	4.24	3.78
AQ	1607	10770	0.47	0.42	0.11	1.12	4.29	3.82
AR	5684	10820	0.47	0.42	0.11	1.13	4.15	3.69
AS	2520	11124	0.47	0.42	0.11	1.12	4.27	3.81
AT	5132	11127	0.47	0.42	0.11	1.13	4.37	3.87
AU	2764	11361	0.47	0.42	0.11	1.12	4.24	3.78
AV	2399	11395	0.47	0.42	0.11	1.12	4.16	3.71
AW	2608	11492	0.47	0.42	0.11	1.12	4.20	3.75
AX	5572	11676	0.47	0.42	0.11	1.13	4.32	3.82
AY	1085	11709	0.48	0.42	0.10	1.14	4.76	4.19
AZ	4241	11752	0.47	0.42	0.11	1.13	4.21	3.74

Figure 12. Measurement points on WATER STAINS and BURNS front.

Table 7. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 12 and related color values and dimensionless ratios.

WATER STAINS chromatic values FRONT								
	h	k	x	y	z	x/y	x/z	y/z
A	2957	247	0.48	0.42	0.10	1.14	4.89	4.29
B	5937	497	0.49	0.42	0.09	1.16	5.80	5.00
C	5983	589	0.48	0.42	0.10	1.14	5.10	4.47
D	5818	2698	0.49	0.42	0.08	1.16	5.89	5.07
E	1073	2751	0.48	0.42	0.10	1.14	4.62	4.06
F	5872	3930	0.48	0.42	0.10	1.14	4.99	4.37
G	1176	6586	0.49	0.42	0.09	1.15	5.14	4.47
H	1174	6589	0.49	0.42	0.10	1.15	5.13	4.46
I	1289	6704	0.48	0.42	0.10	1.14	4.67	4.11
J	4108	6840	0.48	0.42	0.10	1.14	5.00	4.39
K	2486	6861	0.48	0.42	0.10	1.14	4.85	4.26
L	3914	7625	0.48	0.42	0.10	1.14	5.06	4.45
M	5957	8033	0.49	0.42	0.09	1.15	5.22	4.55
N	4040	10583	0.48	0.42	0.10	1.14	4.84	4.26
O	1112	10705	0.49	0.42	0.10	1.17	5.11	4.39
P	5565	10768	0.49	0.42	0.09	1.16	5.36	4.63
BURNS chromatic values FRONT								
	h	k	x	y	z	x/y	x/z	y/z
AA	1895	494	0.50	0.41	0.09	1.22	5.34	4.40
AB	4747	718	0.49	0.41	0.10	1.20	4.95	4.11
AC	1931	1023	0.50	0.41	0.09	1.21	5.89	4.87
AD	4718	1944	0.50	0.41	0.10	1.20	5.20	4.32
AE	1922	2165	0.49	0.41	0.11	1.19	4.40	3.68
AF	1277	2245	0.45	0.41	0.14	1.12	3.24	2.90
AG	4760	2932	0.49	0.41	0.10	1.21	4.87	4.02
AH	1912	3125	0.49	0.41	0.10	1.21	4.91	4.05
AI	5319	3254	0.45	0.41	0.14	1.11	3.26	2.95
AJ	2500	3369	0.47	0.40	0.13	1.18	3.73	3.16
AK	4685	7260	0.50	0.41	0.10	1.22	5.06	4.16
AL	5194	7434	0.50	0.42	0.08	1.17	5.92	5.05
AM	1444	7469	0.50	0.42	0.09	1.20	5.57	4.65
AN	4204	7515	0.48	0.41	0.11	1.20	4.31	3.61
AO	1875	10497	0.48	0.41	0.11	1.18	4.50	3.81
AP	5257	10854	0.47	0.40	0.13	1.16	3.71	3.19

Figure 13. Measurement points on WATER STAINS and BURNS back.

Table 8. Reference table of the position in the (h, k) coordinate system of the measurement points in fig. 13 and related color values and dimensionless ratios.

WATER STAINS chromatic values BACK								
	h	k	x	y	z	x/y	x/z	y/z
A	3082	93	0.48	0.42	0.10	1.14	4.94	4.35
B	5951	953	0.48	0.42	0.10	1.14	4.85	4.26
C	1196	970	0.48	0.42	0.10	1.14	5.02	4.41
D	1119	3022	0.48	0.42	0.10	1.14	4.81	4.23
E	6008	3204	0.49	0.42	0.10	1.15	5.13	4.46
F	1188	4430	0.48	0.42	0.09	1.14	5.17	4.54
G	1254	6339	0.48	0.42	0.10	1.14	4.70	4.13
H	5850	6461	0.47	0.42	0.11	1.13	4.33	3.85
I	5668	6604	0.48	0.42	0.11	1.13	4.42	3.90
J	5854	7762	0.48	0.42	0.11	1.13	4.46	3.95
K	1167	7796	0.48	0.42	0.10	1.14	5.07	4.44
L	1107	8322	0.48	0.42	0.10	1.14	4.70	4.14
M	1169	8760	0.48	0.42	0.09	1.14	5.19	4.54
N	2678	9647	0.48	0.42	0.10	1.13	4.61	4.09
O	3082	93	0.48	0.42	0.10	1.14	4.94	4.35
P	5951	953	0.48	0.42	0.10	1.14	4.85	4.26
BURNS chromatic values BACK								
	h	k	x	y	z	x/y	x/z	y/z
AA	2632	214	0.50	0.42	0.08	1.21	6.01	4.99
AB	1797	514	0.50	0.41	0.09	1.20	5.32	4.42
AC	5103	1653	0.49	0.41	0.09	1.20	5.29	4.43
AD	2158	1695	0.49	0.41	0.10	1.20	4.91	4.09
AE	5118	1989	0.50	0.42	0.09	1.20	5.82	4.85
AF	4801	2779	0.50	0.41	0.10	1.20	5.22	4.34
AG	2536	3704	0.49	0.41	0.11	1.19	4.61	3.87
AH	2238	3716	0.50	0.42	0.08	1.20	6.20	5.17
AI	5158	8019	0.50	0.41	0.09	1.21	5.38	4.43
AJ	4406	8115	0.46	0.41	0.13	1.12	3.42	3.05
AK	2098	8244	0.49	0.42	0.09	1.18	5.45	4.61
AL	4890	10349	0.49	0.41	0.10	1.21	4.75	3.92
AM	5234	11741	0.48	0.41	0.11	1.16	4.47	3.84
AN	2236	11774	0.49	0.42	0.09	1.18	5.33	4.51
AO	2632	214	0.50	0.42	0.08	1.21	6.01	4.99
AP	1797	514	0.50	0.41	0.09	1.20	5.32	4.42

Table 9. Dimensionless ratio range and averages of the analyzed features.

	x/y <i>min</i>	x/y <i>max</i>	x/z <i>min</i>	x/z <i>max</i>	x/y <i>average</i>	x/z <i>average</i>	x/y <i>min</i>	x/y <i>max</i>
Body image	1.12	1.15	4.32	5.25	1.13	4.73	1.12	1.15
Background	1.11	1.13	3.87	4.54	1.12	4.21	1.11	1.13
Blood	1.15	1.19	4.77	5.70	1.17	5.16	1.15	1.19
Waterstains	1.12	1.16	4.33	5.88	1.14	4.96	1.12	1.16
Burns	1.10	1.21	3.23	6.20	1.18	4.90	1.10	1.21

3.2 Results on body image

It can be seen from the plot in Figure 14 that the body image points, placed close to the area of blood, are characterized by x/z values greater than 5. Those points were found on the face and on the neck: the areas in question can be interpreted as typical of body image soaked with blood resulting from injuries on TS man's face and derived from the crown of thorns.

There are, as lower extreme, a series of feature points (ratio x/y goes from 1.12 to 1.13, and ratio x/z goes from 4.32 to 4.58) which overlap with the values area determined for the background: many of the image points that falling in the above mentioned value ranges, are located in the feet, the legs and lower back areas of the TS man.

Figure 14. Plot of chromatic values ratio of all TS details.

3.3 Results on body image

It can be observed from the plot in Figure 14 that there is a not clear colorimetric separation between background and the body image: the color values change with continuity from the typical tone of the body image to those of the background, with a zone of interpenetration between the two "clouds" of data. This evidence is in agreement with some hypotheses of the body image formation that indicate it as the result of a premature aging of the linen caused probably by an radiative effect. Under this assumption, in fact, it is possible to hypothesize that the linen coloration occurred in a progressive manner, with varying intensity depending by the distance body-cloth.

The partial overlap of the values obtained for both, the image and the background, indicates a gradual color transition which extends along a narrow band of values, comparable for the two discussed features.

In order to verify a possible correlation between the color change and the distance from between cloth and body, some points close to the head of the TS man were taken where there is no apparently trace of the body image.

The typical values of these points have a values range for x/y that goes from 1.12 to 1.13 with an arithmetical average of 1.12, while for the x/z ratio the values range goes from 4.25 to 4.52 with an arithmetical average of 4.39.

The author assumed that the chromatic variation can be related to a radiative effect (the same that could have originated to the body image), which has acted with variable intensity depending on the distance from the emission generation point.

3.4 Results on blood stains.

The "cloud" of values resulting from the color sampling on the blood appears positioned in the upper side of the plot used to represent the data (Fig. 14).

It is possible to identify the range of values within which scourge wounds are placed: the x/y values ranging from 1.15 to 1.18 and the x/z ranging from 4.99 to 5.69.

In the lower part of the diagram (Fig. 15), characterized by x/z values of less than 5, the measurements results of the blood spilled by the feet and by the pulse of the Man of the Shroud can be seen.

Some color samplings have been performed on the chest's blood stain and on the visible blood stains outside of the body image, especially near to the left arm and near both feet on the front and back side of TS. A correlation between the blood of the chest and the one of the feet can be observed (Fig. 16), but the outside-arm blood seems different, this is also confirmed from visual examination of this feature.

Figure 15. Plot of blood chromatic ratio values.

3.5 Results on water stains.

The color results of sampling on the edges of the tracks that are supposed to have been left by the water in a period prior to the Chambéry's fire, are mainly located in the area occupied by the values ratio results obtained for body image (Fig. 14), overlapping the same.

Analyzing the results (Fig. 17), it appears evident how the traces left by water (or maybe by another liquid) are comparable in colorimetric terms with the findings on the body image.

3.6 Results on burns

The last series of color sampling, regards the colorimetric characterization of the burns left on the Shroud by the Chambéry's fire. It can be seen from the plots (Fig. 14 and 17) that the results of the dimensionless ratios place themselves mainly on the right side of the plots.

Figure 16. Blood stains comparison plot.

Figure 17. Plot of water stains and burns chromatic ratio values.

4 An application

The created database has been useful for some study on TS features, performed by comparing new color samplings with the database measurements. Considering that the colorimetric values of TS's features are placed in "clouds", more than one measurement for the same TS detail is needed, because must to be evaluated the data trend.

So some study on symmetrical spots (Fig. 18) present on the glutes Man of the Shroud were conducted. These features, whose classification is still debated among researchers, appear located at the vertices of two triangles placed symmetrically to the axis of the back. This traces have blood stains appearance and some experts speculate that they may be traces of blood derived from the wounds generated by a pair of "tridents" on which TS man was forced to sit during the crucifixion.

By a visual inspection, these details appear surrounded by circular halos that can be traced to the serum which has been supposedly gathered around the wounds. For the author they appear too regular in shape and too extended to make possible to assimilate the traces left by blood serum.

A careful observation of this features points out that the central part of the spots appears so confused as to make the weave of the fabric not recognizable. This characteristic was not found in the details related to the blood stains. It may also be noticed that the tone of the central part goes from a very dark brown to a red-orange: also this feature has not been found on the blood stains. It can be assumed that the analyzed details were not originated by blood spilled from wounds.

In order to have more indicative elements, the analysis was carried out by performing more measurements on this circular stains. The results obtained on color value ratios can be observed in the plot reported in Figure 19 and they can be traced back to the typical values found for the burns.

The analysis of the evidence gathered and the assessments made tend to rule out that the currently analyzed details could be related to traces of blood, but rather to burns.

Figure 18. Position of analyzed unknown detail.

5 Conclusions

A colorimetric measurement process has been developed which allowed to obtain a TS calibrated quantitative image with $\pm 4\%$ uncertainty relative to the XYZ color values. This result was achieved by comparison and correction of a digitalized photography made by G.Durante in 2002, with a previous published color analysis performed in CIE XYZ color space by P. Soardo et al. in 1978. The color samplings on digital image were made by using a common photographic software (Paint Shop™ Pro©) with which the values of the single RGB color channel were read by means of the histogram function.

With the TS calibrated image, accurate color measurements were made possible and by properly interpreting the obtained results it was possible to analyze and classify some features.

The color characteristics of body image, background, blood stains, water stain and burns were been investigated: the results give some information like the continuous color transition from background to image.

From a colorimetric point of view, the results on the blood stains have allowed to note that the area occupied by the blood is separated from that generated both from the background and from the body image. Differences between the color values of the blood derived from scourge wounds and the one flowed out from the deepest wounds were also identified. A feature on which future studies can be performed concerning the alleged blood outside the left arm: from colorimetric analysis it did not seems to have the typical colorimetric features found on other bloodstains.

The water stains, are ranked in the plot (Fig. 14) above those determined for the body image, extending also in a similar way: this result could suggest some possible correlation between body image and water stains.

The verification made by new colorimetric measurements on features, not analyzed during database construction, gave the expected results, also providing some additional information for example on visible details on the glutes of the TS Man.

Figure 19. position of the glutes unknown stains color values in burns-blood values "cloud".

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