INNOVATIVE OPTIMISED LIGHTING SYSTEMS FOR WORKS OF ARTS

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ABSTRACT
This paper presents the experience of INRIM in lighting the Turin Shroud at the last 2010 Turin Shroud exhibition. The lights set up was based on the INRIM (formerly IEN) method to light a work of arts, able to predict which source is able to assure the colour perception of the specimen as it would be if lighted by a reference source. In this lighting an innovative source solution using a special set-up was used.

Keywords: Colour perception, lighting works of arts

1 INTRODUCTION
Lighting a works of art represents a difficult exercise of balancing two different and opposite aspects: perception and conservation.
INRIM (formerly IEN) developed a method, initially called IEN method ables to overcome the known difficulties of the Color Rendering Index method when polychromatic surfaces are exposed to low light levels. Even the suggestion of Kruthoff diagram can fail, especially because its strong hidden correlations with light source emission spectrum and specimen spectral characteristics.

2 THE INRIM METHOD
The INRIM methodology defines the luminous source properties, with the aim of achieving the best colour rendering (working on the emission spectra) and of avoiding colour and objects degradation (working on the illuminance level). The colour rendering properties of different types of lamps, or of a combination of them, is evaluated taking account of the spectral reflection factor of several points of the work of art and, especially for painting, of the type of illumination available to the artist.
The final result of the designed lighting system can be studied through photorealistic images of the work of art,
obtained using an improved radiosity technique for computer graphics, on calibrated monitors, starting from the environment photo-colorimetry characterization (sources, surfaces and inter reflections). In this way realistic images with high colour fidelity and correct luminance levels are obtained and the validity of the design is verified through subjective controls.

2.1 The INRIM method details
CIE recommends a method [1] for evaluating the colour rendering index of light sources on the basis of resultant colour shifts of 14 standardised colour samples, called CRI. This well-known method was modified using directly the spectral reflectance factors of surfaces of colours present in the work of art surface, instead of the limited set of CIE references. This solution permits a better design of the lighting installation, highlighting the difference, in the perceived colours, between light sources presenting the same value of the CIE colour-rendering index.

The methods consists of several steps and is fully described elsewhere [2][3]:
- measurement of the spectral reflectance of the objects (spectral characterization of the work of art).
- definition of the correct source (or mix of sources) with the procedure derived from the CIE colour rendering index method but with the measured spectral reflectancies of the lighted object;
- calculation with a modified radiosity algorithm of the photometric and spectral reflected radiation considering the influence of the spectral reflections in the environment (including BRDF behaviour) around the object (e.g. walls);
- visualisation on a calibrated monitor for subjective verifications of the object the same colour perception as it would be if it is lighted by the reference source

2.2 Perception at low illuminance levels
Literature [4][5] and standards, generally report a permitted illuminance level for sensible materials of 50 lx with an annual dose of 50 klx h/year for extremely sensible materials and 150 klx h/year for sensible material, but some authors prefer lower values of illuminance. These low levels modify the original colour rendering conditions in which the works was created, but this shift can be partially corrected if the light source spectra are accurately selected. The simplest correction is to refer to the Krüthoff diagram, but there is not large consensus about the results showed in the diagram. More comfortable data arise from recent research on mesopic vision but it still a first line research. For this reasons it is preferable to verify the results on calibrated monitor and adapt accordingly.

3 Source management improvement
The method can be used with traditional or LED sources but it has been improved considering the properties of computer controlled light projectors usually used in multimedia shows.
Computer controlled light projector are very interesting and useful “tunable” light source, their emission can be, with a series of strong constraints, ad hoc modulated in order to reproduce a desired colour perception, correct spectral
external influences (i.e. protective glass or ambient light that induce spectral alterations) and intensity gradients. The possibility to modify the emitted spectrum not in the whole, but with a good spatial resolution is the main advantage in this application. This means that with ad hoc mathematical constraint it is possible to operate on single spatial elements of the focused light projected. In this way punctual spectral and intensity correction can be made.

3.1 Source characterization

The radiation emitted by such a type of computer controlled light projector, shall be deeply characterized in terms of:

- Spectral distribution;
- Parameters set up influences;
- Reproducibility;
- Stability.

The light source emits light in three independent bands. Each band is characterized and managed as single source.

1) Considering a reference illuminant (selected following historical reasons or other constrains), for each measured spectral reflectance, the:
- trichromatic coordinates $x_r, y_r, z_r$;
- trichromatic components $X_r, Y_r, Z_r$;
- chromatic coordinates $L_r, a_r, b_r$

are evaluated.

2) For each emitting band of the source, with normalized spectrum respectively $S_1, S_2$ and $S_3$, the "mixture" source is defined with spectrum $S_{k,123}$:

$$S_{k,123}(\tilde{\varepsilon}) = k_1 S_1(\tilde{\varepsilon}) + k_2 S_2(\tilde{\varepsilon}) + k_3 S_3(\tilde{\varepsilon})$$

where $k$ is a parameter contained between $k = 0$ (no band $S_i$ present) and $k = 1$ (full band $S_i$ present).

3) For every combination of the three bands spectra (or a suitable subset), $S_{k,123}$ is obtained by varying $k$ in steps of 0,1 with $k \in [0,1]$ and for every sample surface, the colorimetric parameters of point 1 are calculated.

4) For every mixture source $S_{k,123}$ considered in point 3, and for the $n$ measured spectral reflectance of the object, the $I_{k,123}^{n}$ index:

$$I_{k,123} = \sqrt{(L_{k,123} - L_r) + (a_{k,123} - a_r) + (b_{k,123} - b_r)}$$

is evaluated. This parameter expresses the chromatic difference between the colour obtained with the source data and the reference colour for a given colour of the specimen.
For each of the \( n \) surfaces the values of \( k_i \) that makes the \( I_{k,123,n} \) index minimal was determined.

In order to satisfy the above constraints it is necessary to fully characterize the light source. Because the new sources are computer controlled, the several different parameters of the source set up can strongly influence in different ways the emission spectrum \( S_1, S_2 \) and \( S_3 \).

4 applications

In early 2000 the IEN method was applied to several important works of arts, Giotto's frescoes Cappella Degli Scrovegni [7] and Leonardo's Cenacolo in order to define which commercial and traditional light source is able to assure the same colour perception of a priori reference source. In 2010 the enhanced INRIM method was applied to study the Turin Shroud Exhibition using a triband projector.

4.1 The Turin Shroud exhibition lighting

The Holy Shroud exhibition - in its more literal meaning of the act to show, display - requires a lighting able to facilitate the visual task of pilgrims to decipher the details of the image in a sufficiently obscured behaviour to not to disturb the concentration and the mystical approach to the cloth and to satisfy ambient parameters for the perfect preservation of specimen and avoid any possible image damage.

Perceive visually the Shroud is not an easy task. The “sign” of the figure that emerges from the background with the many details of the passion is somewhat masked by other factors such as burns or stains on the fabric. Also in terms of colour, as shown by the measurement (carried out by IEN-INRIM in 1978 and 1998) of spectral reflectance of the image differs minimally from that of the background fabric.

Basically the perceived image is the result not of a difference in colour (like the “red” blood), but in brightness, appearing much darker than the background.

In this special lighting set up the main problems to overcome are:

- Geometrical constraints (specular reflections from the protective sheet of glass, shadows, illuminance uniformity) due to the light position vs Shroud position;
- Spectral constraints due to the presence of a thick and green security glass and the Shroud itself;
- Perception constraints due to conservation, religious behaviour, image characteristics (difference in brightness rather in colour);

4.1.1 Geometrical constraints

The geometrical position of Turin Shroud shrine was fixed, aligned with the church centre axis, and the same for the positions of lighting sources, imposed by the pilgrims paths positions, security (the sources must be out of reach) and clear view of the shrine form the church entrance.

All these geometrical constraints produced shadows, specular reflection and illuminance disuniformity that was possible to correct only because of the computer controlled lights.

In fact INRIM (formerly IEN at that time) arranged the Turin Shroud Exhibition since 1978. For the past exhibitions, incandescent light projectors with filter were used, but this kind of sources did not permit a complete compensation of
shadows and illuminance disuniformity. Figure 1 shows the illuminance disuniformity on the security glass before of application of mathematical algorithm for the correction.

Fig. 1
Illuminance disuniformity on the security glass

Fig. 2
Security glass spectral transmittance factor (0/45 and 45/45)

Fig. 3
Colorimetric coordinates of some Shroud points

4.1.2 Spectral constraints
The main spectral constraint is related to the influence of the security glass those spectral transmittance factor (0/45 and 45/45) is show in Figure 2. The green glass colour influences the colour perception of the Turin Shroud.

4.1.3 Perception constraints
The emission spectrum of the sources was calculated with the triple aim of:
• to perceive the colors of the Shroud as if it were illuminated by diffuse light of the sky, mimicking the ancient Shroud exhibition where the Shroud was exposed outdoors;
• increase the contrast between image and background, thereby making more visible signs of the Man of the Shroud;
• minimize the incident light, keeping it below the regulatory limits, to optimize the conservation conditions.

As show in Figure 3 the colour differences between image and background are not clearly different and the algorithm used was indispensable for optimizing the exhibition conditions.
CONCLUSIONS
This paper presents the improvements of the INRIM method especially designed for the use of new electronic sourc-
es with strong emitting bands, like LED or digital projector. The most relevant improvements involve the possibility
to spatially modify both spectral and intensity parameters in order to satisfy behavior influences or constraints, like
geometrical influences on illuminance uniformity, specimen spectral variations due to condition of exhibition …
The method was recently applied to the 2010 Turin Shroud Exhibitions using digital projector, and was able to over-
come all the constraints imposed by the conditions of exhibition and conservation of the Shroud.

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REFERENCES

1 Commission Internationale de l’Eclairage: Method of measuring and specifying colour rendering properties of light sources,
CIE 13.3
2 P. Iacomussi, G. Rossi, P. Soardo, L. Fellin: A new method for studing lighting design for works of arts, Proceedings of Lux
Europa 2001 The 9th European Lighting Conference, Reykjavik (IS) 2001
3 P. Iacomussi, G. Rossi, M. Sarotto, P. Soardo: An imaging spectroradiometric system for the works of art measurements, Pro-
cedings of IMEKO XV World congress, Osaka (JP)1999
4 Commission Internationale de l’Eclairage: On the deterioration of exhibited museum objects by optical radiation, CIE 89.3
5 Commission Internationale de l’Eclairage: Control of damage to museum object by optical radiation CIE 157
6 norma UNI 10829:1999 Condizioni Ambientali di Conservazione
7 Il restauro della Cappella degli Scrovegni, Luce di Giotto, Luce per Giotto, L. Fellin, P. Iacomussi, G. Rossi, P. Soardo, editor
M. Basile, ISBN 88-84912-28-8