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ILLUMINATION OF PAINTINGS, GRAPHIC ARTS, PRINTED PRODUCTS, PHOTOGRAPHS: PROBLEMS AND POSSIBLE SOLUTIONS

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ABSTRACT

The article analyses the major problems of museum lighting. Possible technical solutions to the mentioned problems relating to each type of exhibited artworks are detailed. The results of the studies used as a basis for these solutions are described.

Keywords: lighting environment, illuminance distribution uniformity, paintings, sculpture, minor forms, glare, interior of palace architecture, fresco, stucco, projection optics, radiation

1. INTRODUCTION

Museum lighting is one of the most complex problems, which requires the application of radically different approaches depending on the type of exhibits.

Moreover, the concept of lighting always depends on the architectural features of a building where exhibits are located.

It is especially difficult to arrange correct lighting in palace museums since the architecture of such buildings was originally designed for another purpose and the lighting equipment contemporary with the time of design and construction fundamentally differs from the current requirements of museum lighting. As a result, a number of seemingly unsolvable problems arises:

– Maintaining of uniform illuminance distribution with significant difference of distances between the exhibits and a lighting device (LD);

– Elimination of highly bright glares on artworks created by light sources (daylighting sources in daytime and artificial ones at night) as well as glares on case glass due to extremely unsuitable built-in lighting and location of built-in light sources;

– Lighting of sculptures in limited exhibition areas not allowing to manage the shadow-forming process.

LDs themselves (chandeliers, wall luminaires, floor lamps, etc.), which are decorations in terms of the interior, often create obstructions for the formation of required light fields accentuating interiors of palace halls, e.g. ceilings with stuccoes or frescoes.

All these problems really seem unsolvable, but invention of new light sources, light emitting diodes (LED), provided they are applied correctly in conjunction with latest achievements in the fields of optics, IT systems, and control systems, allows not only to solve these problems but also to do it without introducing visible changes in the classical interior of a palace.

2. LIGHTING OF PAINTINGS

Preservation of paintings exhibited in museums is provided by means of lighting standards. Unlike production, educational, and other areas where lower limits are specified, for museums, higher limits, which cannot be exceeded in any case, are specified. For each type of exhibits, illuminance values are specified [1]. For instance, it cannot exceed 50 lx for fabric, newsprint paper, and watercolour, 150 lx for oil paintings, and 500 lx for precious metals and jewels.

As for the paintings, it is obvious that these values do not comply with conditions in which they were created, therefore, we see not what was intended by an artist but distorted colours.

Analysis of conditions in which the works were created shows that the range of illuminance values is rather wide. Here's what Leonardo da Vinci wrote about it [2]: "For portraits, you should have a special studio: a long, four-corner yard with width of ten cubits and length of twenty cubits with walls painted black, with a roof stab above the walls and a canvas shade arranged in such a way so that it provides protection from the sunlight. Without extending the shade, you should paint only at the beginning of twilight or when it is cloudy or foggy. This is the perfect light." Reconstruction of these conditions shows that illuminance of the easel may be within the range of (400–600) lx. Van Gogh created a number of his works at night wearing a straw hat and placing candles on its brim and wrote about it [3]: "I often feel that night is much more colourful than daytime." Simulation of such conditions shows illuminance of (15–20) lx. In addition, Van Gogh painted his landscapes at daytime with easel illuminance of (3500–4500) lx.

So, what prevents us from seeing the art from the author's perspective? The thing is that it is necessary to eliminate or minimise aggressive components of the LD spectrum, the ultraviolet and infrared radiations, since the former causes direct destructive impact (dissipation of molecular links) and the latter promotes deterioration of materials by speeding-up chemical reactions by means of temperature rising. The danger of the ultraviolet radiation is enhanced by its so-called cumulative effect, i.e. accumulation of results of such impact.

This all is relevant in case of daylighting or using LDs with conventional light sources: incandescent lamps, tungsten halogen lamps or metal halide lamps but becomes irrelevant after transfer to LED light sources [4].

Application of fluorescent light sources is not preferable too both because of the significant flicker of the luminous flux and relatively low value of colour rendering index (CRI) caused by spectral lines of radiation [4]. However, conventional light sources harmful to art objects have been being changed by widely spread and rather powerful white LEDs with ultraviolet and infrared parts of the spectrum reduced to values safe for all types of colourants or fully eliminated as shown in Fig. 1.

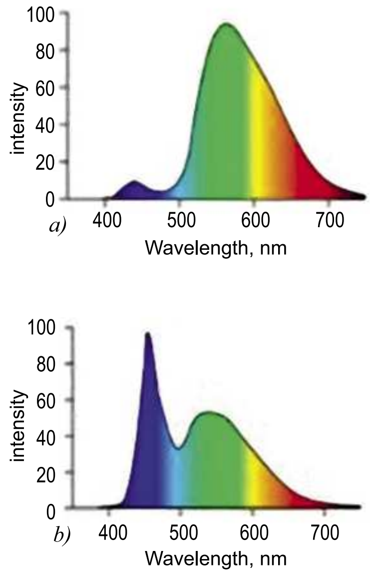


Fig. 1. Spectrum specifications of LED with various correlated colour temperature: a) warm white LED; b) cold white LED

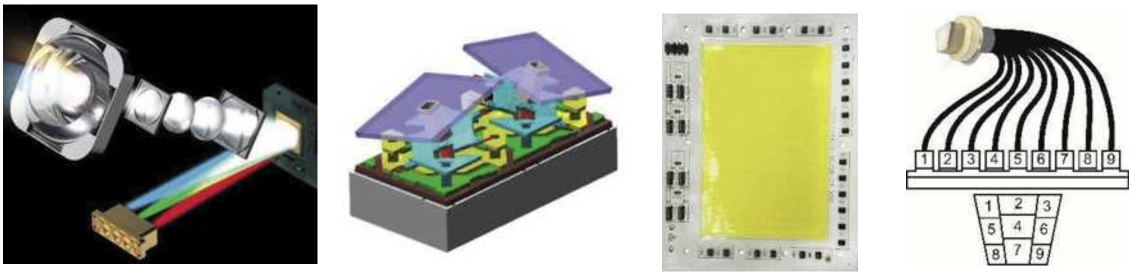
It is obvious that preservation of exhibits is a very important problem and specification of new requirements to storage and exhibition conditions of fine art objects due to the appearance of seemingly safe light sources is a problem, which requires serious studies. In its turn, development of the regulatory framework should allow approaching museum lighting problems in a more flexible way with the consideration that each piece of art, whether it be a painting, a sculpture, a fresco, a mosaic, an installation, etc., is a unique object requiring an individually chosen method of lighting. The only common moment here is the requirement to provide uniformity of illuminance distribution and maximum CRI value, compliance with which is one of the most serious problems of museum lighting.

All the other parameters should comply with the conditions as of the moment of creation of the object as much as possible, subsequently, they may differ greatly, i.e. they should be variable. These parameters are:

– Absolute values of illuminance which may vary, in particular, due to the different distance of observation, for example, of a fresco, a mosaic, or a painting;

– Colour temperature of the resulting radiation, which may vary due to different conditions and daypart in the course of creation;

– The necessity to eliminate glares caused by light sources and interior elements, which may vary due to different lighting conditions;

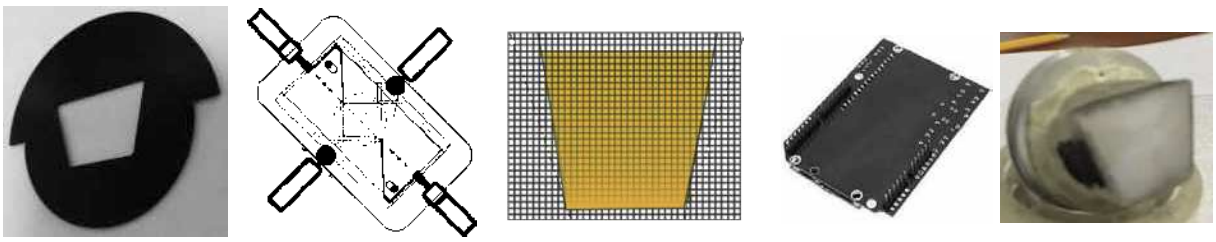


a) b) c)

Fig. 2. Alternative technical solutions for provision of uniform distribution of illuminance: a) *DMD+DLM* technology; b) a set of LED matrices with differential control of active elements; c) fibre-optic image converter with flexible cables and differential input

a) b)

Fig. 3. Lighting of paintings with conventional overhead LDs: a) overview of a gallery; b) vertical illuminance distribution over a painting



a) b) c) d) e)

Fig. 4. Devices for provision of required contrast level between an illuminated object and a background: a) removable aperture; b) an aperture controlled remotely; c) remotely controlled matrix; d) liquid-crystal plate; e) fibre-optic image converter

– Contrast level, i.e. the ratio between luminance values of the object and its background.

Thus, correct lighting of a piece of fine art requires solving of a number of the problems listed in Table 1, which shows that it is possible only with conceptually new approaches to design of luminaires and formation of special light environment for each specific exhibit. That is why museum lighting is considered the most complex nowadays.

It is obvious that the mentioned challenges can be solved within a uniform technical solution, i.e. one structure of a LD. It is also clear that LDs may be based on different technical principles depending on specific application conditions. That is why this article examines key technical solutions for beating these challenges and questions of their integration with structures of existing LDs.

3. ARRANGEMENT OF UNIFORM ILLUMINANCE DISTRIBUTION ON A PAINTING SURFACE

As noted above, the achievement of the high degree of illuminance distribution uniformity

Table 1. Known Methods of Resolving Problems of Paintings Lighting

Problems of lighting	Conventional methods
Increase of illuminance level up to the one complying with the conditions at the moment of creation with absolute preservation of paint layer	No solution
Provision of uniform illuminance with relatively close location of light sources	No solution
Provision of variable colour temperature with maximum possible CRI	No solution
Elimination of glares caused by light sources in different lighting conditions	Replacement of a luminaire to a lower position
Contrast management with different sizes of a lighted object	Management of the shape of light beam
Universal design at relatively low price	Design and technological solutions

on a painting surface is one of the museum lighting major problems, therefore, it is one of the main tasks in the design course of a LD providing such uniformity.

Analysis of the technical capabilities of the solution has shown at least three ways to solve this task:

– Application of the *DMD+DLM*[1] technology [5, 6], development of fibre-optic image converters with differential input;

– Application of LED matrices with differential control of active elements.

The operation principle of these technical solutions is explained in Fig. 2.

Among the listed methods, the *DMD+DLM* technology is the most universal one (Fig. 2a). It is based on the simultaneous formation of both a light beam with a pre-defined shape and luminous intensity distribution in this beam by means of a set of micro mirrors with two-axis control.

Another method, as much universal as the previous one, is the application of LED matrices with differential control of active elements [7–9] shown in Fig. 2b.

This method is distinctive with application of a multi-matrix containing separate mini-matrices with dimensions of 1.34×1.34 mm united in groups, each of which, depending on the light distribution area and uniformity degree requirements, contains 6, 5, or 4 mini-matrices with individual power supply of each group, thus providing the required degree of illuminance distribution uniformity on the surface of an illuminated picture.

Another advantage of such a matrix is the structure of the aluminium-oxide board, which is a nanoporous framework with increased thermal conductivity (≥120 W/K×m as compared with 3 W/K×m of conventional aluminium boards), which makes it unnecessary to use a radiator, ventilator, or another cooling system, which is extremely important for operation in a museum environment.

The third quite simple illuminance distribution adjustment method is the application of a fibre-optic image converter [10] (Fig. 2c) with the shape of its output end reflecting the luminaire lens focal plane projection shape of the illuminated object and which is assembled of separate fibre-optic bunches with focused LED radiation of necessary capacity supplied on their input end.

Luminous flux adjustment of each of these light sources allows not only to get a high degree of illuminance uniformity but also to control the illuminance level within a wide range.

4. PROVISION OF THE REQUIRED LEVEL OF CONTRAST

In different museums, it is quite possible to face situations when a light spot formed by a luminaire can be seen around a painting (Fig. 3). Analysis of this method of lighting has shown that it not only irritates sight but also usually causes significant illuminance nonuniformity of a painting (Fig. 3b) and relatively small contrast between the lighted object and its background. Such method causes an increase of illuminance level of the painting, which in some cases causes “shining” of a frame, which bothers perception even more.

These negative effects can be reduced by means of the luminous flux formation with a pre-defined shape and size with the simultaneous control of the background luminance, for instance, by means of:

[1] *DMD* is a *Digital Micromirror Device*. *DLM* is a *Distributed Lock Manager*

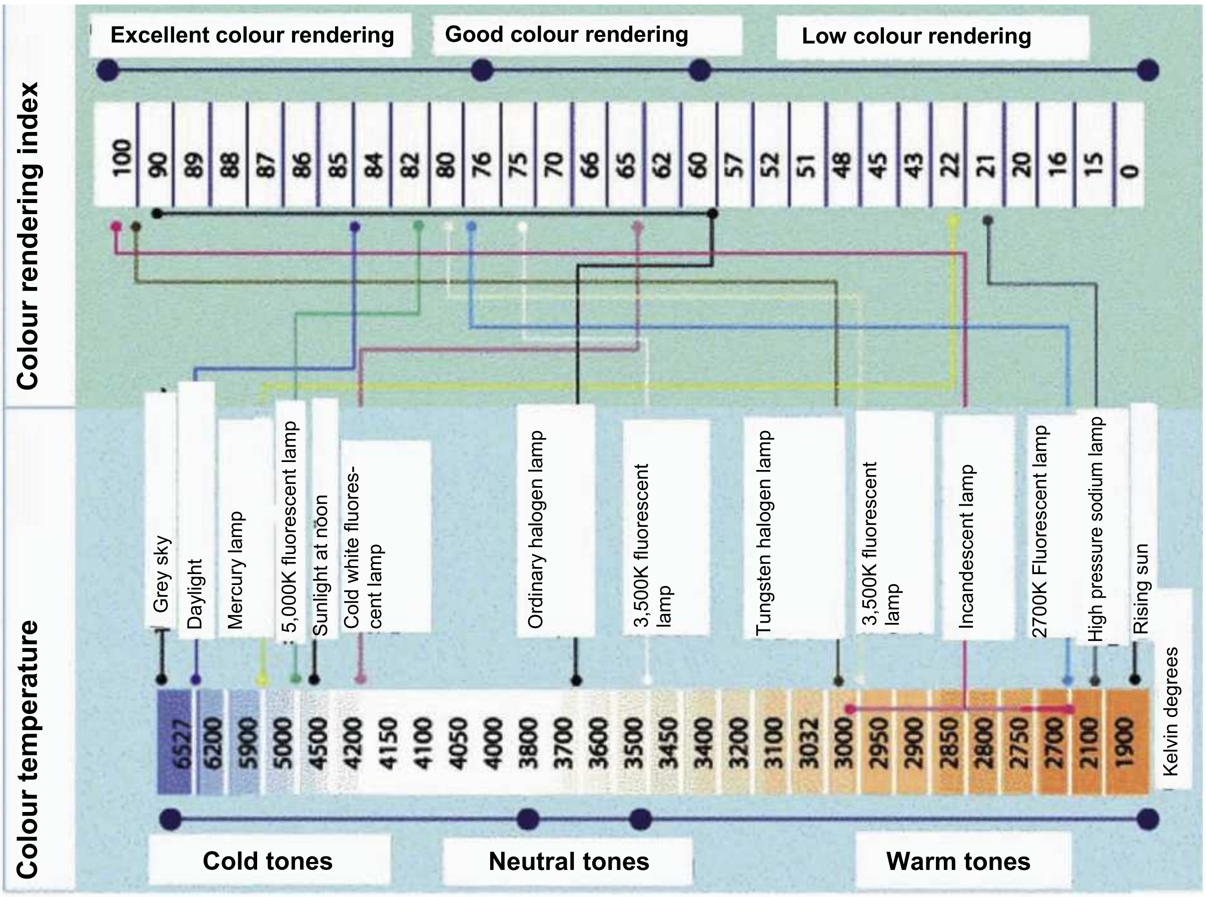


Fig. 5. Scheme of colour temperature and CRI of different light sources

– Projection-type apertures replaced depending on the shape and size of the illuminated object (Fig. 4a) or controlled remotely by means of an electric drive (Fig. 4b);

– Matrices (Fig. 4c);

– Liquid-crystal plates (Fig. 4d [11]);

– Fibre-optic image converters (inside the LD with increased CRI requirements and requiring an optical mixer for mixing radiation from various spectrum of the light sources) (Fig. 4e).

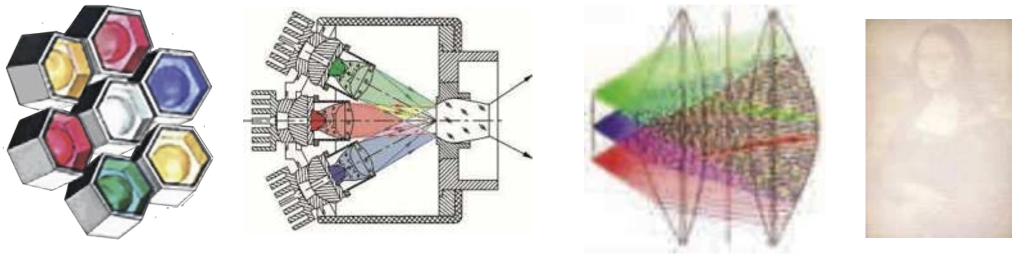
5. PROVISION OF MAXIMUM POSSIBLE VALUE OF CRI AND COLOUR TEMPERATURE

When conventional light sources were used (incandescent lamps, gas discharge, and fluorescent light sources), the maximum possible value of CRI was reached usually by selecting a design of a particular LD. Naturally, as we can see on a scheme shown in Fig. 5, the number of variants of the maximum possible value of CRI was rather limited. The situation is made worse by the fact that the options providing required values of CRI turn out to be non-applicable due to other parameters, in this case, due to the unacceptably high share of the infrared component in the radiation of these LDs.

The appearance of LED makes the situation totally different as it allows to get high values of CRI in case of reliable mixing of radiation with different chromaticity. Application of a fibre-optic image converter [12] shown in Fig. 6 as a mixer may be taken as an example of the technical solution for this task as, simultaneously with the mixing of radiation from seven monochrome LEDs, it forms the shape of luminous flux required for solving a specific task. In this case, CRI of 95 is reached.

With another option [13], if it is necessary to reduce the length of a LD, a thin fibre-optic bead with the thickness of just 3 mm can be used and, working in conjunction with a two-component projection optical system and a diffusive plate, it allows to get CRI of 96–98.

In addition, an alternative option to provide high values of CRI equal or exceeding 95 is the application of complex phosphor.



a) *b)*

Fig. 6. Options to achieve high values of CRI: a) a set of 7 monochromatic LEDs of 5 colours with a fibre-optic image converter; b) a set of 34 LEDs of 5 colours with a fibre-optic bead and a diffuse filter at radiation output

a) *b)*

Fig. 7. Lighting of paintings in an enfilade: a) daytime; b) night time

6. ELIMINATION OF GLARES CAUSED BY LIGHT SOURCES AND INTERIOR ELEMENTS

The most frequently encountered problem of museum lighting causing discomfort for visitors is the availability of glares created by daylighting sources and artificial ones at night time, which is easy to show (Fig. 7). This effect is especially significant in palace museums where paintings located in enfilades, which are relatively narrow halls with large windows and LDs installed overhead, will always “shine” under an influence of light sources.

Glares are inevitable for paintings located on mounts installed at an angle to windows (Fig. 8a) and even more for pieces of art located in cases or behind protective glass**.** Even Raphael did not manage to avoid it (Fig. 8b).

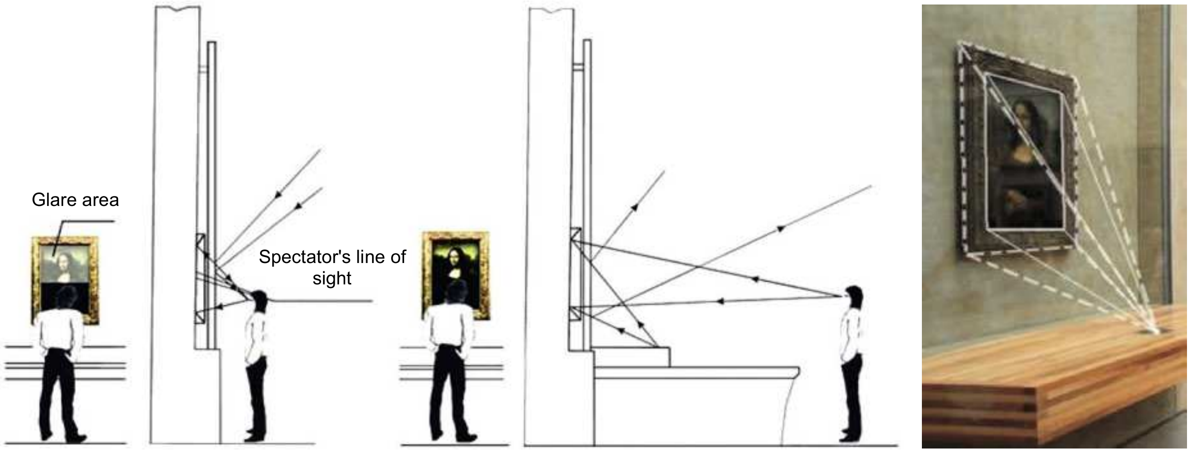
It is obvious that overhead artificial lighting can be avoided neither, especially in palace museums, and since the luminous flux is not sufficient for lighting of paintings, additional special LDs are required with their power supply via busbars spoiling palace architecture. However, the most important thing is that, due to optical laws, they form rather

a) *b)*

Fig. 8. Glares on paintings located perpendicular to a window: a) without protective glass; b) with protective glass

a) b) c)

Fig. 9. Examples of overhead lighting of paintings with special LDs



a) b) c)

Fig. 10. Ray path in the process of glare formation:
a) with overhead lighting; b, c) with lower lighting

bright glares on exhibits preventing the normal perception of the latter (Fig. 9).

The solution eliminating this effect shown in Fig. 10 is obvious: it is necessary to change the direction of radiation from light sources, which has been first implemented for the lighting of Mona Lisa in the Louvre [12].

The analysis of ray path shown in Fig. 10 shows that with overhead lighting (Fig. 10a), the position of a glare on the portrait may take almost a half of the surface of a picture depending on the position of the spectator whereas with lower lighting (Fig. 10b) there are no glares at all.

The glares on objects exhibited in cases are eliminated by means of compensating opposing diffuse beam (Fig. 11) providing the value of luminance on the protective glass equal to the value of luminance from outer light sources or even exceeding it. Herewith, taking into account that the external illuminance forming glares constantly change due to the changes of external factors, it is necessary to make this system self-adjusted, i.e. provide it with illuminance and colour temperature feedback sensors. According to the analysis, this allows either to get rid of glares or to sufficiently reduce their impact on the perception of pieces of art.

The values of illuminance on protective glass created by glare-forming light and by opposite beam compensating this glare as well as of illuminance on the surface of the lighting object are shown in Table 2.

7. LIGHTING OF LARGE WORKS AND MULTIFIGURED COMPOSITIONS

The lighting of large works (larger than 1.5 m) usually requires the application of several LDs united into one system. In this case, complications are caused by the connection of LDs as overlapping of non-controlled light beams causes non-uniformity of illuminance in the resulting distribution of light. Another obvious obstruction for qualitative lighting of works with dimensions exceeding 4.0×3.0 m is the inevitability of glares in case of overhead

Table 2. Illuminance of Elements of an Image Case and Eyes of a Spectator

Illuminance on the protective glass, lx		Illuminance, lx	
From external light sources	From the opposing light beam	At distance of 0.5 m from an object	On an object
200	450	140	250
100	450	120	200
50	2910	670	300
50	2300	420	250
50	1140	270	150
50	360	80	80

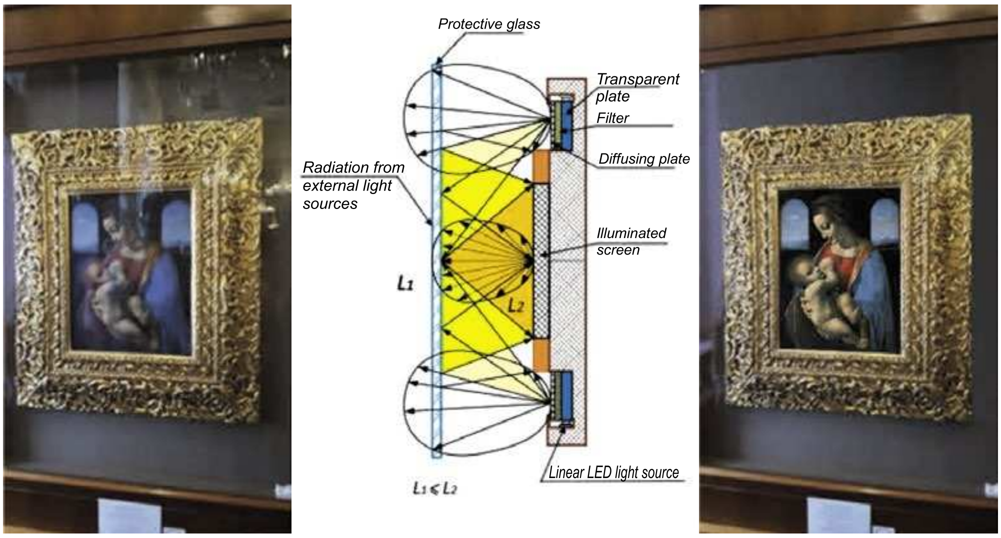


Fig. 11. Lighting with an opposing light beam

installation of LDs and rather large dimensions of a lighting installation almost excluding a possibility of lower installation of equipment due to the significant reduction of exhibition area.

The specified problems are possible to be solved with the application of LED matrix sets with the differential control of active elements as light sources. In this case, LDs are installed as shown in Fig. 12a and 12b so that the edges of light spots from neighbouring LDs with lower luminous intensity (Fig. 12e) overlap each other on the surface providing uniform distribution of illuminance all over the surface of a painting and total elimination of glares.

8. SYNTHESIS OF TECHNICAL SOLUTIONS IN SPECIAL LDS FOR LIGHTING OF PAINTINGS

The first attempt to implement a part of the above mentioned technical solutions in a united LD was made in 2005 in the course of the reconstruction of the Gioconda hall in the Louvre for the lighting of Mona Lisa, which required the development of a special LD (Fig. 13).

The LD contains seven monochromatic LEDs (green, red, blue, orange, and white) with their radiation focused on the input end of the fibre-optic image converter acting simultaneously as a colour mixer and a contouring element and then going to the remote-controlled round aperture and projecting optical device.

The detail description of the design of this LD proposed and implemented by Pharos-Alef LLC is given in [12]. The specified LD was constantly working for 8 years without changing its specifications.

Its modernisation relating to the value and uniformity of illuminance distribution was made in 2013 in the course of the Louvre Efficient Lighting project.

The modernised LD contains 34 single-chip and multi-chip LEDs, an optical mixer consisting of a collimator, an aperture, a fibre-optic mixer, a dif-

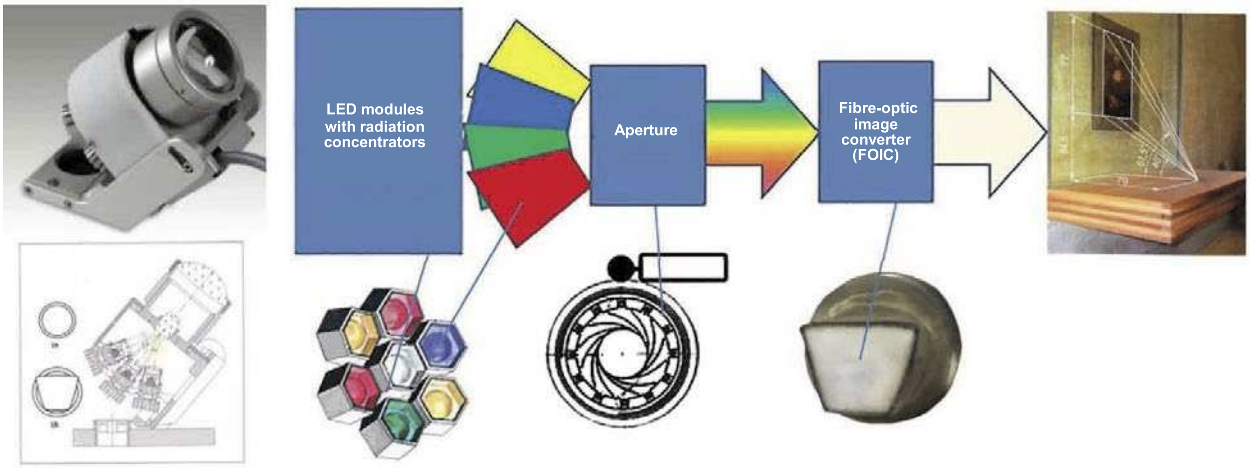


Fig. 13. The design and elements of the LD for lighting of Mona Lisa (2005)

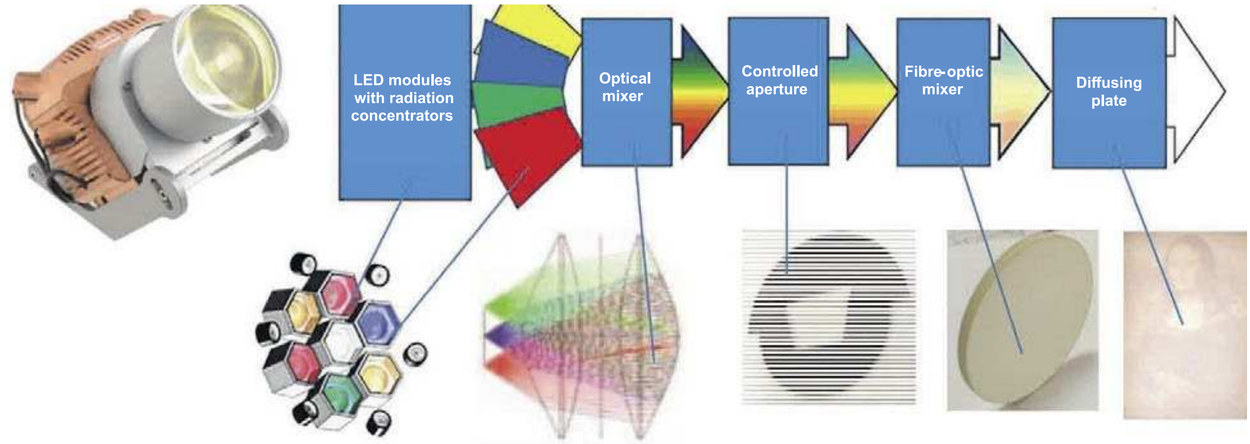


Fig. 14. The design and elements of the LD for lighting of Mona Lisa (2013)

a) b)

Fig. 15. Lighting of Lorenzo Lotto's Christ Carrying the Cross: a) with a traditional method of mixing of artificial and natural illumination; b) with the proposed LD

fusing plate, and a projecting aspherical lens (not shown) (Fig. 14) [13].

As a result, it was possible to eliminate distortions of the light beam spot on the illuminated object specific for ordinary lenses and to increase CRI from 95 to 98.

This modernised LD described in [13] in detail has been working in the Louvre since June 2013.

Not so long ago, an attempt was made to update and to simplify this LD making it universal, applicable for operation with objects of different shape and size, and for this purpose, a multi-matrix was

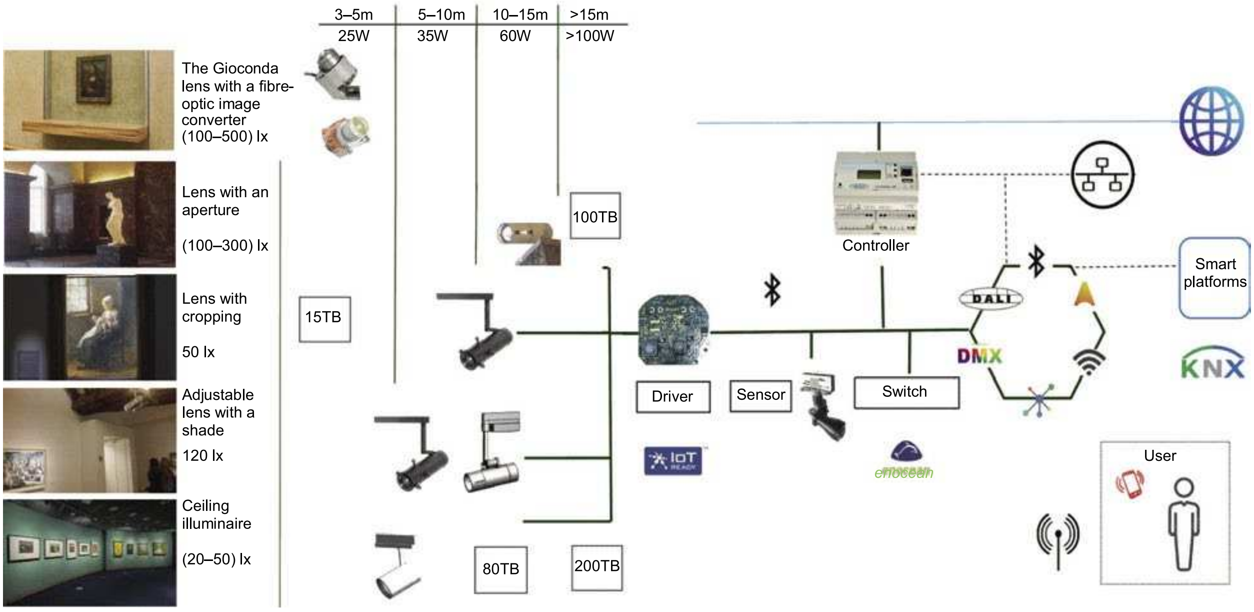


Fig. 16. Major specifications of LD for lighting of paintings and its control system scheme

used as a controlled aperture and a device providing uniform distribution of illuminance on the surface of a painting. To reach high values of CRI, the multimatrix contains LEDs with complex phosphor providing CRI equal to 93–95. As a result, a LD providing solutions to the listed problems was developed and its testing confirmed its practicability (Fig. 15).

As it was already noted in section 6, there is a capability to use another method of paintings lighting with the application of an opposing light beam formed by a diffusing structure with luminous flux end input. Such a method allows not only to provide uniform lighting with radiation of required chromaticity at a sufficient illuminance level but also to reduce the impact of glares significantly.

However, the tests showed that this method has limitations only for objects located behind glass at a distance of at least 3 cm.

Therefore, for solving the specified problems, in cooperation with *Sklear* (Germany), Pharos-Alef LLC has developed a series of such LDs and an adjustable control system for them. Major specifications of these LDs and the structure of the control system are shown in Fig. 16.

9. LIGHTING OF WATERCOLOURS, TEMPERA, GRAPHIC ARTS, AND TEXTS

Alongside with the lighting of paintings, the lighting of graphic arts and text objects (almost everything made on paper) has its special aspects related to their storage, exhibition, and perception. These special aspects basically relate to the susceptibility of paper to accelerated deterioration under the influence of light. It is obvious that maximum impact is caused by ultraviolet and infrared parts of the spectrum, which, as we have seen, can be eliminated. Herewith, as practice shows, the condition of a medium and therefore the piece of art, in general, are to some extent influenced by other parts of the spectrum, which makes curators not only reduce the illuminance value down to 50 lx [14] but also shorten the exhibition time by covering objects with light-proof fabric.

The majority of graphic works of all possible techniques are exhibited upright on walls. At the same time, a small format of graphic works and examination of small features of the images requires relatively small distance between a spectator and an object which in most cases is protected with glass. As a result, the spectator sees his/her reflection in the glass, which significantly prevents the perception of the exhibited piece of art. In addition, everyone is convinced, though not without reason, that this “inevitable evil” can be improved only with the application of expensive non-reflective glass. This method works to a great extent, but, unfortunately, not always. The analysis of causes of the spectators reflection in front of exhibits and capabilities of contemporary light sources shows that non-reflective glass is almost useless at high values of

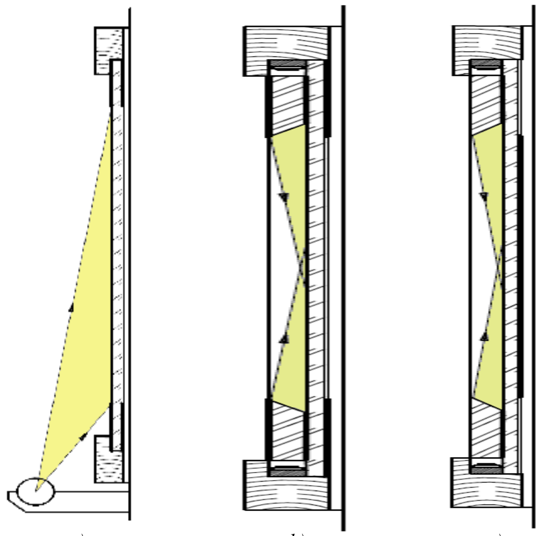


Fig. 17. Schemes of lighting of graphic works and photographs: a) lighting from below with an external LD; b) frontal lighting of an object with a dark mat; c) frontal lighting of an object with a light mat

luminance of daylighting and artificial light sources causing glares. As shown in section 2, this problem can be resolved alternatively by increasing contrast, which can be achieved in several ways:

– The lighting by means of a lower LD up to limit of luminance on the paper;

– Frontal lighting of an object against a non-lighted mat background;

– The lighting of an image and a mat with differently directed radiation.

It is obvious that in any case radiation incidence angles should be as high as possible for the energy impact minimisation of its refracted part.

Implementation of these methods of a LD taking special aspects of graphic art lighting is shown in Fig. 17a (lighting from below) and 17b (an increase of contrast). This effect is expressed even more with the lighting of a dark image and a light mat with differently directed radiation as shown in Fig. 17c.

10. CONCLUSION

The problems of museum lighting listed in the article should not be considered comprehensive in any case as it doesn't describe such important questions as LDs made as parts of palace architecture, methods of harmonisation of technical means preserving pieces of art, and other aspects of museum lighting environment formation with a wide range of architectural solutions existing. The proposed methods of solving these problems are not to be considered comprehensive either. They just demonstrate capabilities of recently created tools for the implementation of tasks in other related areas.

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