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ILLUMINATION CRITERIA IN IMAGING SYSTEM DESIGN FOR SECURITY APP--ETC(U)

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ILLUMINATION CRITERIA IN IMAGING SYSTEM DESIGN
FOR SECURITY APPLICATIONS

by

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Abstract. Of paramount importance in the design of an effective imaging system for security applications, such as perimeter and area surveillance, is the establishment of artificial illumination criteria which are compatible with the requirements of both the imaging cameras and human observers. The "American National Standard Practice for Protective Lighting," ANSI A85.1-1956(R 1970), lists requirements for the illumination of boundaries. These requirements apply to direct visual observation by guards. In television viewing, the much reduced dynamic range of the sensor relative to the human eye and camera responsiveness introduce a new problem. The MITRE Corporation has developed a set of criteria for perimeter lighting in an Imaging System. The requirements express the minimum maintained average illumination within the lighted strip and the maximum variation of the minimum level at any point on the ground from the average level. A prototype imaging/illumination system was developed and tested which incorporates high pressure sodium vapor lamps, roadway luminaires and silicon diode array television cameras. Tests were conducted in an operational environment.

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This paper discusses the criteria and performance requirements of the prototype closed circuit television lighting installation. It also presents a discussion of pertinent human factors, engineering and economic considerations that should be included in the implementation of protective lighting/imaging systems.

Introduction

Closed circuit television (CCTV) is assuming an increasingly important role in the security field as a means of providing remote surveillance and intrusion alarm assessment. This paper will present the role of artificial illumination for outdoor CCTV systems used for security and surveillance and will discuss the development of lighting criteria which are compatible with the requirements of both the imaging cameras and human observers.

A television camera is a device capable of converting visual images into electrical signals for transmission in a suitable medium (e.g., coaxial cable, telephone lines or RF link) to remote centers where timely reproductions of the original images are produced on monitor/displays. Figure 1 is a simplified block diagram of a CCTV system.

Modern technology has developed long life silicon diode vidicon (SDV) television camera tubes which are more sensitive than their predecessors, and immune to damage by very bright sources and image burn-in. Technological advances have permitted miniaturization of the TV camera and have made possible unattended operation for extended periods of time. An important feature of the SDV camera (equipped with an appropriate lens and light control) is that it is capable of producing an image of a scene illuminated with as little as 0.1 foot-candle upward to that provided by direct sunlight. At levels of scene illumination in the 10 to 15 foot-candle range, excellent TV pictures can be obtained which are noise free and have low lag characteristics. Furthermore, pictures acceptable for security applications can be achieved with scene illumination as low as 0.25 foot-candle. These pictures, however, are likely to exhibit some graininess and may exhibit some lag, in particular if objects in the scene are in fast motion or if the camera must make a fast pan. In order to ensure that high quality pictures will be obtained for nighttime surveillance, the CCTV system will require artificial illumination both in an amount suitable to allow the system to produce good rendition of the scene and of sufficient uniformity to facilitate its viewing on the monitor.

Extensive laboratory and field experiments have been performed by MITRE to determine CCTV system and lighting system architectures to enable security guards to perform the functions of surveillance and alarm assessment. This paper will provide guidance

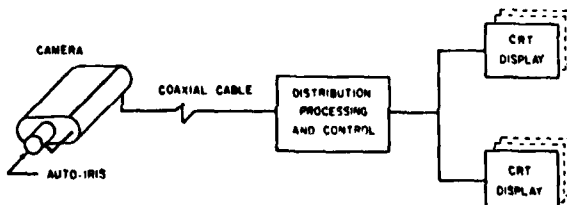


Figure 1. CCTV System

on lighting based on this experience. The lighting system discussed is compatible with the "American National Standard Practice for Protective Lighting," ANSI A85.1-1956 (R1970).

Lighting System Design/Characteristics

The design of a lighting system involves many variables including economics and visibility related factors. The ultimate goal of the system design is to illuminate the critical portions of a secure area in such a manner that human observers can make quick and accurate detection and alarm assessment. In addition, the illumination must be such that the cameras are able to produce a rendition of the scene of sufficient contrast for adequate visibility without the presence of dead spots or other forms of image degradation. Some of the steps involved in the design of a lighting system are:

- a. Determination of the minimum level of illumination which provides good visibility for both human observers and cameras.
- b. Specification of the degree of illumination uniformity which enables the camera to produce a satisfactory scene. Illumination provides effective visibility for both human observers and cameras only when it is sufficiently uniform.
- c. Selection of an appropriate light source which is compatible with both human visibility and color discrimination requirements, and camera spectral sensitivity.
- d. Selection of luminaire type which provides the optical control characteristics (i.e., light distribution) required for the specific lighting application and system configuration.
- e. Formulation of lighting equipment emplacement scheme (system architecture) which provides high quality illumination. This involves selecting luminaire mounting height in conjunction with pole spacing and distance from the critical area to be illuminated.
- f. Comparative calculation of alternate configurations to determine relative factors of uniformity, economics, glare, maintenance, and constraint considerations.
- g. Measurement/calculation of the illumination level actually achieved by the best alternative configuration in a sample test.

It should be recognized that in many instances, changes intended to optimize one factor will adversely effect another and the resultant total quality of the installation may be degraded.

Of the many variables that influence the performance of the visual tasks associated with surveillance and alarm assessment, the key ones are¹ the level of illumination, and the spatial pattern of illumination (luminance contrast). These variables are important both when the visual task is performed directly by a human observer and when the observer performs the task remotely with the aid of a CCTV system, the primary difference being only in the amount of intrascene luminance that each system is capable of handling.

Unlike the human eye, a CCTV system has a limited intrascene dynamic range. This limitation is attributable to dynamic range limitations of the SDV tube and the monitor display as well as to the limitations of the average human observer to distinguish between 7 and 10 different shades of gray in a television picture. With the present state-of-the-art a CCTV system can

handle at best a 20:1 intrascene luminance contrast without incurring loss of picture detail.

Scenes in which heavy shadows or very bright spots are present will complicate the visual task. During the day, when the scene illumination cannot be controlled, special techniques may be required to ensure proper TV rendition. Two potential techniques are discussed in Reference 2. Under nighttime conditions, notwithstanding weather effects, the scene illumination can be controlled by proper illumination design, so that high contrast, glare, etc. are eliminated or alleviated.

Lighting Equipment Selection

In the process of designing a lighting system, attention is first focused on the availability of lighting equipment. The designer is presented with a wide range of equipment, most of which finds some application around the security area but none of which is universally adaptable for all purposes. Illumination engineers tend to classify lighting systems by the general type of lighting produced and the general layout of luminaires. They are typically described as general, local, localized general, or supplementary; and by the type of luminaires used.

Luminaires

Four general types of luminaires are available for use in protective lighting. The four types are: 1) floodlights; 2) street lights; 3) Fresnel lens luminaires; and 4) searchlights. The choice of luminaire for a particular lighting system will depend on the light pattern distribution, the tendency to cause objectionable glare under normal conditions, the mechanical construction and convenience of servicing the light source selected, and the overall suitability of the unit for the application at hand. A brief description of the four types of luminaires follows.

Floodlights are designed to form the light flux generated by a lamp into a broad beam so that it may be projected into distant points. They may be used for illumination of boundaries, open areas, buildings, and for local emphasis of vital areas.

Streetlights or roadway luminaires are characterized by their light distribution which may be symmetrical or asymmetrical. A symmetrical distribution is one in which the distribution of light and candle power are approximately the same in any vertical plane passing through the optical axis of the luminaire. Luminaires with symmetrical light distribution find application in lighting large areas, where the luminaire may be located centrally with respect to the area to be lighted, and at gate entrances and exits. Asymmetrical luminaires direct the light by reflection and/or refraction in order to achieve higher utilization of the light. The asymmetrical distribution finds application in situations where the location of the luminaire with respect to the area to be lighted is restricted and under which conditions the symmetrical distribution would be wasteful or ineffective (for example, applications where it may be necessary to locate the luminaire within the protected area and deliver the light largely outside the fence surrounding the boundary; and for roadways where the pole, of necessity, must be placed outside the limits of the roadway but the effective light must reach the road surface).

The Fresnel lens luminaire delivers a fan-shaped beam of light and may be used to illuminate the approaches to the secure area to inflict glare on the would-be intruder while maintaining the guard force concealed in darkness. Its application is limited to locations where advantage may be taken of its unique characteristics without causing objectionable glare to neighboring activities.

Searchlights deliver a narrow beam of light. A typical application of a searchlight is to supplement other lighting equipment

by providing highlights on particularly sensitive areas within the facility and to permit exploration of areas within and outside the facility by the guards directing the light to the area in question.

The types of luminaires found best suited for perimeter illumination, when CCTV is employed, are the floodlights and the streetlights (roadway luminaires). The streetlights are preferred, however, because the asymmetrical light distribution simplifies the system architecture when designing for uniformity of illumination.

Light Sources

The types of light sources or lamps which are available and which might be considered for secure area illumination applications are: incandescent, fluorescent, mercury, metal halide, high pressure sodium (HPS), and low pressure sodium (LPS). The mercury, metal halide, and HPS belong to the class of lamps known as high intensity discharge (HID). Table I presents a summary of the luminous efficacy and rated life of these lamps. Rated life figures are a function of lamp wattage, operating position, operating voltage, temperature and burning cycle.

Table I. Lamp Luminous Efficacy

	Luminous Efficacy Average Lumen/Watt	Rated Life Average Hours
1. Incandescent	10-35	1,000 +
2. Fluorescent	30-83	4,000 +
3. Mercury	30-65	24,000 +
4. Metal Halide	85-100	6,000-15,000
5. High Pressure Sodium	95-140	20,000 +
6. Low Pressure Sodium	130-180	20,000 +

If luminous efficacy and rated life were used as the sole criteria for the selection of the most suitable type of lamp for security applications, the choice would be quite simple. However, many other lamp characteristics and properties are important for consideration in the selection of lamps for these applications, since a lighting system must satisfy constraints imposed by human observers and imaging camera characteristics. A prime consideration in the selection of lamps is the visibility provided for both human observers and television cameras.

In the case of human observers, the effect of color rendition on the ability to identify objects is important. An object within an illuminated area reflects selected wavelengths of light. To observe the "true" color of a given object, it is necessary that the wavelengths which comprise that color must be present in the source of illumination. In addition, the level of illumination must be of such a magnitude that photopic (color) vision is obtained. In the case of a television camera, it is important that sufficient light energy is emitted from the lamp in the portion of the electromagnetic spectrum to which the TV camera is sensitive so that a useable video signal is produced. In this paper it has been assumed that the TV cameras employed are equipped with a silicon diode array vidicon. The SDV is sensitive not only to visible wavelengths of light but also to infrared wavelengths. This type of vidicon has a spectral responsivity characteristic illustrated in Figure 2.

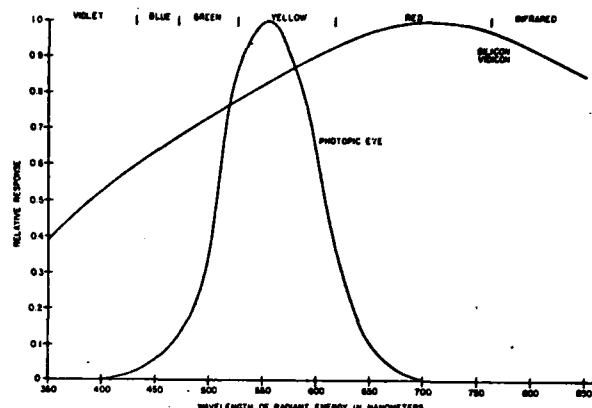


Figure 2. Spectral Responses of Eye and Silicon Vidicon (Relative)

Each type of light source possesses a unique spectral power characteristic. Reference 3 contains representative spectral power curves of HID and incandescent lamps. Using the color rendition property of each light source, a quantitative measure of the suitability of the source for use with the SDV camera can be derived. This measure is the amount of spectral energy utilized by the camera to produce an output signal in relation to total energy available. The higher the value, the greater the degree to which the illumination is suitable for use with the SDV. There is a very small variation in these ratios for the various light sources. Thus, the choice will rest on efficacy, color rendition capability, and lamp-luminaire configuration.

The LPS, which would be a prime choice on the basis of efficacy and life expectancy, is not at all suited for applications in which a human observer might require color discrimination for identification because of its near monochromaticity. For example, consider a situation in which a white identification badge is exchanged for a yellow badge for access to a secure area. Under LPS illumination, both badges might appear identical in color unless closely compared side by side. On the other hand, LPS is a satisfactory light source for the operation of SDV equipped TV cameras and would be considered a good choice for lighting secure areas solely under TV surveillance, since color discrimination in this case is not a factor in the recognition and identification of an intruder.

Both incandescent and fluorescent light sources offer a great deal of flexibility to achieve the desired degree and accuracy of color rendition. However, both consume a great deal of power compared to HID types and have low rated lifetime.

The HPS, even though it produces predominantly gold-amber illumination, has sufficient output in various visible wavelengths to provide for satisfactory color rendition and human observer acceptance. This light source is favored for security applications based upon its long life expectancy and its ability to be used with many types of luminaires.

Lighting Configuration

Considerations

There are likely to be some restrictive constraints imposed on the physical layout of a security lighting system. For example, terrain and perimeter features, location and means of mounting lights with respect to the perimeter barrier and placement of television cameras all have an effect on system configuration. The

ving situations might arise: 1) the combination of uniform level of illumination requirements and lamp placement tions could limit the selection of a suitable luminaire/lamp guration from those which are commercially available; or minaire placement restrictions may result in non-optimum al design in that shadows might be created by perimeter is, and glare might become offensive (especially when the is wet). In addition, equipment placement constraints may t in non-optimum placement of TV cameras to obtain an istructed view of the area/perimeter to be protected and, sfore, limit the surveillance and alarm assessment capability ided by the imaging system.

A prototype configuration will be described below which rates the placement of lighting fixtures and cameras which expected to produce the desired minimum illumination ot-candle), and uniformity ratio not greater than (3:1), and coverage in a single fenced boundary. The design of this con- ration, which is patterned after Illuminating Engineering lety (IES) roadway lighting guidelines,⁴ emphasizes maximum ormity rather than minimum light level. The minimum aver- horizontal light level is determined from the basic equation:

$$\text{Average Foot-Candles} = \frac{\text{Lumens} \times (\text{Coefficient of Utilization}) \times (\text{Light Loss Factor})}{\text{Spacing Between Luminaires in Feet} \times (\text{Width of Strip in Feet})}$$

coefficient of utilization represents the percentage of rated up lumens which will fall on either of two strip-like areas of inite length, one extending in front, and one extending in back the luminaire when the luminaire is level and oriented over the ip in the same manner in which it was tested by the manufac- er. This coefficient is read from utilization curves which are sible, for various types of luminaires, from the luminaire nufacturer. The light loss factor is estimated or determined perimentally and takes into consideration such factors as lamp terioration and dirt accumulation.

Uniformity is expressed in terms of the average level of illu- ation on the design area and the lowest value at any point in the ea. The ratio of the average to the minimum value is taken as ie measure of uniformity. To study the uniformity of the illu- ation and to determine the level of illumination at any specific int in the illuminated area, use is made of the "iso-foot-candle" irve. The iso-foot-candle curve is a graphical representation of ints of equal illumination connected by a continuous line. In der to make these curves applicable to all conditions, they are esented for a given mounting height, and the horizontal dis- nces between lights are expressed in ratios of the actual distance the mounting height. Correction factors for other mounting ights are usually given in tabular form with the iso-foot-candle irves. These curves, for various luminaire type and lamp com- bitions, are available from the luminaire manufacturer. These sta afford a practical tool for the initial layout of a lighting rstem.

Prototype Configuration

Figure 3 is a plan view and the profile of the prototype light- ing configuration including the location of TV cameras to cover ie area. The luminaires used are streetlights (roadway Type III GE-M 250A)). The lamps are 150W HPS. The luminaires are cated over the fence to eliminate fence shadows in the viewing rea as well as to minimize reflected glare from the fence. The nstallation provides for one of the main features generally re- quired in protective lighting, (i.e., minimal illumination in the terior of the secure area) thereby enabling the security force to perate from a relatively dark area.

This configuration provides a measured average horizontal nital illumination of 1.9 foot-candle over the 30 feet wide outer

strip, and a uniformity ratio of 2.35. The predicted design values, based on the methods described, were: average illumination - 2.1 foot-candles, and uniformity ratio - 2.3. A higher than re- quired initial value allows for losses as a result of lamp deteriora- tion and dirt accumulation on the luminaire surface. In this design a 35% loss factor has been taken to account for the light level degradation after three years of operation with only relamping of burned out lamps. This gives a maintained illumination level of 1.2 foot-candles. A sample of the actual light distribution is given in Figure 4.

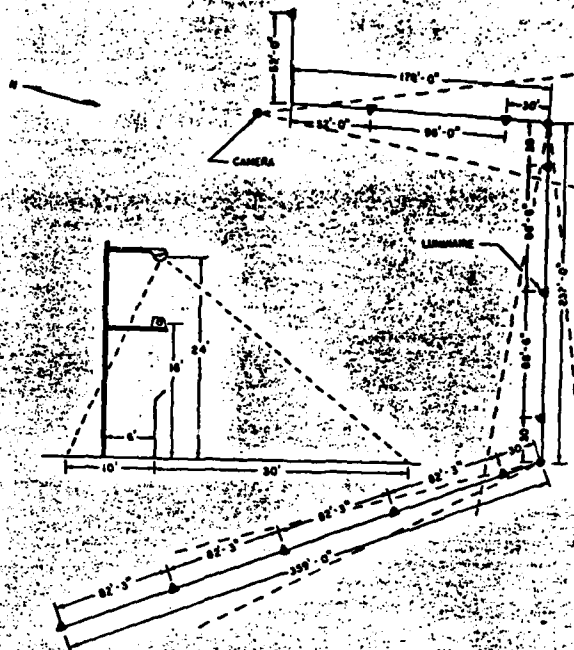


Figure 3. Lighting Configuration (Plan View & Profile)

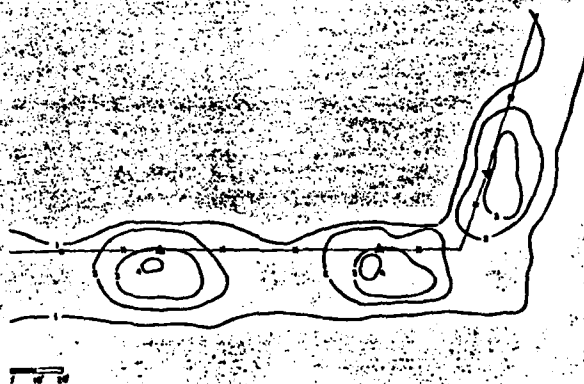


Figure 4. Light Distribution (Iso-foot-candle)

Tests conducted by MITRE have shown that an SDV camera CCTV system produced pictures of good quality with this level of illumination and uniformity. Figure 5 is a CCTV monitor display rendition of the scene illustrated in Figure 4. Security guards were also able to perform direct visual tasks effectively under these lighting conditions.

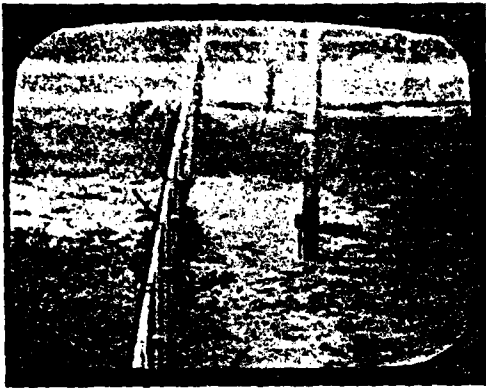


Figure 5. TV Display of Lighted Perimeter (Single Fence)

A similar lighting configuration was featured in CCTV alarm verification system tests conducted at an operational Air Force installation overseas. The critical viewing area was the area between fences of a double barrier configuration. A CCTV system using SDV cameras covered the portions of the perimeter out of direct view of an operator situated in an observation tower within the protected area. The illumination provided by the lighting configuration was more than adequate for both direct visual observation and for remote observation via CCTV.

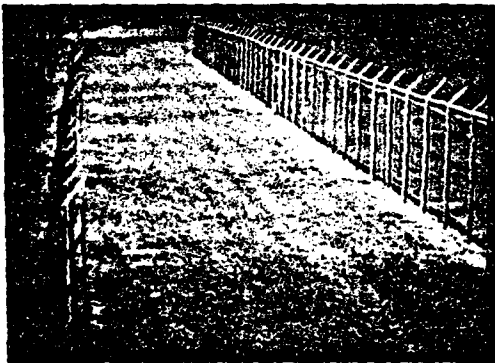


Figure 6. TV Display of Lighted Perimeter (Double Fence)

A section of that installation is shown in Figure 6 as a monitor/display picture of the area covered. Since the emphasis here is to get the best uniformity in the critical viewing area (i.e., between the fences) there will be some shadow present in the outer area due to the fabric of the outer fence. Such a compromise will have to be made in the design of the lighting system where double fences are required for security.

Conclusions

The high pressure sodium lamp with Type III luminaire is the best combination for the implementation of perimeter security lighting where closed circuit television using silicon diode array vidicon cameras is employed. The design must take into consideration the level of illumination and the light distribution on the ground adjacent the fenced barrier. The value of the minimum maintained average level of illumination will depend on the sensitivity of the TV camera used. For the SDV, 1.0 foot-candle was satisfactory. This level is also compatible with tested levels for effective visual assessment. This average value provided effective visibility when the uniformity ratio, expressed as the ratio of the average illumination value to the lowest value at any point in the prescribed illuminate area, did not exceed 3 to 1. A side benefit of the prototype configuration described herein offers low operating power consumption per kilometer of perimeter illumination (7.2 kw/km).

Acknowledgment

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1. IES Lighting Handbook, 5th ed., Illuminating Engineering Society, 1972, Section 3.
2. G.O. Sauermann and F.G. Benkley, "Improvement of CCTV Surveillance Through Selective Contrast Enhancement and Weighted Averaging Control," 1978 Carnahan Conference on Crime Countermeasures, May 1978.
3. IES Lighting Handbook, op cit, p. 8-20.
4. Ibid., Section 20.

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