CONF-9207102--8

Received by OSTI

*Initial Laboratory Evaluation of Color Video Cameras

SAND--91-2579C

DE92 018274

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ABSTRACT

Sandia National Laboratories has considerable experience with monochrome video cameras used in alarm assessment video systems. Most of these systems, used for perimeter protection, were designed to classify rather than identify an intruder. Monochrome cameras are adequate for that application and were selected over color cameras because of their greater sensitivity and resolution. There is a growing interest in the identification function of security video systems for both access control and insider protection. Color information is useful for identification purposes, and color camera technology is rapidly changing. Thus, Sandia National Laboratories established an ongoing program to evaluate color solid-state cameras. Phase one resulted in the publishing of a report titled , "Initial Laboratory Evaluation of Color Video Cameras (SAND91-2579)". It gave a brief discussion of imager chips and color cameras and monitors, described the camera selection, detailed traditional test parameters and procedures, and gave the results of the evaluation of twelve cameras.

In phase two six additional cameras were tested by the traditional methods and all eighteen cameras were tested by newly developed methods. This report details both the traditional and newly developed test parameters and procedures, and gives the results of both evaluations.

DISCLAIMER

This Work Was Performed at Sandia National Laboratories and Sponsored By The Department of Energy Under Contract DE-AC04-76DP00789

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INTRODUCTION

Because color cameras may enhance the performance of video security systems, Sandia National Laboratories established an ongoing program to evaluate color cameras. In the initial phase, twelve color cameras were evaluated and the results were published in SAND91-2579. Those cameras along with six others were evaluated by traditional test procedures for sensitivity, resolution, the signal to noise ratio (S/N) and intrascene dynamic range. All eighteen were tested by newly developed test procedures for white balance, color rendition under different light sources, and low light level color rendition. A discussion about camera selection, test parameters, procedures, and results follows.

TEST CAMERAS

Cameras were selected for evaluation based on manufacturer-specified performance. Some were chosen because of high resolution and others because of sensitivity. Selections represented different solid-state technologies to determine any distinct characteristics inherent to a particular technology. Cameras were also chosen from different manufacturers to attain a broad representation of camera designs. Table 1 lists the cameras that were selected for this evaluation.

Table 1. *Test Cameras (Listed in alphabetical order.)*

MANUFACTURER	*MODEL NUMBER*	*FORMAT* *IN.*	*MM*	*IMAGER TYPE**	*PIXELS H x V*
Burle	**TC-252**	2 / 3	11	CCD / FT / MFIS	768 X 492
Cohu	**6800**	1 / 2	8	CCD / FT / SFIS	739 X 484
Cohu	**8200**	1 / 2	8	CCD / ILT / MFIS	768 X 493
Hitachi	**VK-C350**	2 / 3	11	MOS / ILT / MFIS	760 X 485
Ikegami	**ICD-800**	2 / 3	11	CCD / ILT / MFIS	510 X 490
Javelin	**JE-3362**	2 / 3	11	MOS / ILT / MFIS	576 X 485
Javelin	**JE-3462HR**	2 / 3	11	MOS / ILT MFIS	760 X 485
Javelin	**JE-3542**	1 / 2	8	CCD / ILT / MFIS	510 X 492
JVC	**TK-880U(L)**	1 / 2	8	CCD / ILT / MFIS	510 X 492
JVC	**TK-980U**	1 / 2	8	CCD / ILT / MFIS	512 X 492
Panasonic	**WV-CL302**	1 / 2	8	CCD / ILT / MFIS	512 x 492
Panasonic	**WV-CL352**	1 / 2	8	CCD / ILT / SFIS	682 X 492
Panasonic	**WV-CL702**	1 / 2	8	CCD / ILT / MFIS	682 x 492
Pulnix	**TMC-574S**	2 / 3	11	MOS / PBPT / SFIS	576 X 485
Pulnix	**TMC-74**	2 / 3	11	CCD / ILT / MFIS	756 X 581
Sanyo	**VDC-4124**	2 / 3	11	CCD / FT / SFIS	800 X 490
Sony	**SSC-S20**	1 / 2	8	CCD / ILT / MFIS	768 x 495
Sony	**SSC-C350**	1 / 2	8	CCD / ILT / MFIS	510 x 492

** CCD = charge coupled device* *FT = frame transfer*
ILT = interline transfer *MOS = metal-oxide semiconductor*
MFIS = mosaic filter image sensor *SFIS = striped filter image sensor*
PBPT = pixel by pixel transfer

TRADITIONAL CAMERA TEST PARAMETERS

The traditional camera parameters that were tested are sensitivity, resolution, signal-to-noise ratio, and intrascene dynamic range. A detailed discussion of each of these parameters can be found in the reports titled, "Initial Laboratory Evaluation of Color Video Cameras (SAND91-2579)", and "An Evaluation of Monochrome Solid State Video Cameras (SAND90-2533)".

Sensitivity

A primary consideration in camera selection is sensitivity. The more sensitive the camera, the less artificial light that has to be provided to produce the desired video signal. An increase in artificial lighting translates into an increase in lighting equipment, thereby increasing the system cost and the operating cost.

A camera should produce a full video signal at higher light levels and, at the lowest light levels, must provide sufficient video signal amplitude to drive a video monitor. Through testing and experience, Sandia National Laboratories staff determined the minimum video signal needed to drive most monochrome monitors effectively is a 40-IRE-unit excursion between peak black and peak white. This amplitude of video signal is sufficient to produce satisfactory image quality without requiring adjustment of brightness and contrast controls. At the time of this evaluation, sufficient data had not been collected to determine the minimum video signal level for color monitors. However, the 40-IRE-unit excursion does provide a reference level for comparing the overall sensitivity of the monochrome cameras with the sensitivity of the chromatic cameras.

Resolution

Another very important consideration in choosing a camera is resolution. Larger zones can be viewed by imagers providing greater resolution. This can reduce the number of cameras and associated mounting hardware and cabling required, thereby reducing the system cost.

High-resolution color solid-state cameras designed for security applications require a resolution of approximately 430 to 460 TV lines of horizontal resolution (compared to 565 to 580 for monochrome cameras).

Signal-to-Noise Ratio

The video signal-to-noise (S/N) ratio directly affects ability to distinguish detail in an image. Although image quality is often subjectively evaluated, metrics can be useful in evaluating this parameter. Video camera signal quality is a function of the amount of noise present in the video signal. This noise content is commonly expressed as a S/N ratio measured in decibels (dB). Camera manufacturers typically specify the S/N ratio at high brightness levels, measuring the illuminance signal with the color information removed by means of a filter. The S/N ratio is rarely specified at low light levels or with the color information included because the noise is considerably greater. Some manufacturers will specify a S/N ratio with the automatic gain control (AGC) circuitry switched off and specify the maximum sensitivity with the AGC switched on. Not all manufacturers make note of these subtle, but significant, differences in their specifications.

Intrascene Dynamic Range

The following information in this section is derived from SAND 90-2533, authored by Donald Greenwold.

Video camera systems are limited in their ability to reproduce all scene luminance levels that exist in a natural environment. Both monitor and camera have limitations in creating and displaying independently discernible levels in gray scale. The standard EIA test chart contains ten gray scale steps with a maximum reflectance ratio of about 30 to 1.

A camera should provide a full video signal. If the full video signal is not produced in the camera, the actual scene information will be compressed into fewer shades of gray than normal. The usual effect on the monitor will be a low contrast, washed-out picture. Image detail may not be distinguishable from the background if the detail is close in luminance value to the background. This is especially a problem in daylight environments. Video assessment in shadows surrounded by bright sunlight create significant problems due to the high scene dynamic range in brightness levels. In these circumstances, a compromise must be made to select the area of prime interest and to ignore the unresolved areas.

TEST PROCEDURES FOR TRADITIONAL TEST PARAMETERS

Test procedures for traditional test parameters can be found in the reports titled, "Initial Laboratory Evaluation of Color Video Cameras (SAND91-2579)", and "An Evaluation of Monochrome Solid State Video Cameras (SAND90-2533).

COLOR CAMERA PERFORMANCE FOR TRADITIONAL TEST PARAMETERS

The results of this color camera evaluation were compared to those of the latest laboratory evaluation of monochrome solid-state video cameras (SAND90-2533).

The minimum usable video signal for monochrome cameras, 40 IRE units peak white to peak black, was used as a reference to compare the sensitivity of the color versus the monochrome cameras. Although considerable progress has been made toward improving color cameras sensitivity, the most sensitive color camera chosen for this evaluation is considerably less sensitive than the most sensitive monochrome camera. The color camera produced the minimum usable video signal with 0.0127 of faceplate illumination, compared to 0.0014 fc for the monochrome camera, a factor of 9.1. The other color cameras required significantly more illumination, ranging from 0.022 to 0.600 fc, to attain the minimum usable video signal.

Manufacturers specify the S/N ratio of color cameras measuring the luminance signal only. The color burst that provides color information and unwanted additional noise has been removed. Measuring the luminance signal only, at the illumination needed to produce the minimum video signal, the S/N ratio for both monochrome and color cameras ranges from 35 to 43 dB. At the full illumination levels (92.5 IRE units) obtained from high-faceplate illumination, the S/N ratio for color solid-state cameras, with the color information removed, ranged from 42 to 46 dB, which corresponds to the monochrome camera measurements.

The horizontal resolution of color cameras is less than for monochrome cameras. The higher resolution monochrome cameras provide 550 to 575 horizontal TV lines, compared to 430 to 470 for color cameras. Although the resolution of color cameras does not equal that of monochrome cameras, a great deal of improvement in the resolution of color cameras is evidenced. Until recently, color cameras produced only around 330 horizontal TV lines.

Table 2 provides the results of this evaluation. Cameras are arranged with the most sensitive camera first, decreasing in sensitivity toward the bottom of the table. When easily selectable measurements were taken with the AGC on. Comments on image quality are noted.

Table 2. Faceplate Illumination Test Data at Forty IRE Units Video Level (Cameras listed By Most Sensitive)

Camera Model	*Faceplate Illumination (Footcandles)*	*ResolutionHorizontal TV Lines*	*Signal to Noise Ratio*	*AGC*	*Notes*
JVC TK-980U	**.0127**	**300**	**38**	**ON**	**VERY NOISY**
PANASONIC WV-CL352	**.022**	**430**	**39**	**ON**	**ONLY 7 GREY SCALE STEPS**
JAVELIN JE 3542	**.026**	**320**	**40**	**ON**	**ONLY 8 GREY SCALE STEPS**
SONY SSC-C350	**.026**	**320**	**37**	**ON**	**NOISY**
COHU 8210	**.028**	**470**	**40**	**ON**	**MODERATE NOISE**
IKEGAMI ICD-800	**.041**	**310**	**32**	**ON**	**VERY NOISY**
SANYO VCD-4124	**.046**	**310**	**32**	**ON**	**NOISY**
BURLE TC-252	**.0463**	**300**	**38**	**ON**	**VERY NOISY**
PANASONIC WV-CL702	**.061**	**410**	**37**	**ON**	**MODERATE NOISE**
SONY SSC-S20	**.061**	**470**	**41**	**ON**	**MODERATE NOISE**
PULNIX TMC-74	**.064**	**340**	**40**	**ON**	**SLIGHT NOISE**
COHU 6815	**.066**	**330**	**35**	**ON**	**VERY NOISY**
PANASONIC WVCL-302	**.091**	**330**	**39**	**ON**	**MODERATE NOISE**
JAVELIN JE-3362	**.120**	**330**	**37**	*** N. S.**	**VERY NOISY**
JVC TK-880U(L)	**.194**	**330**	**40**	**ON**	**SLIGHT NOISE**
JAVELIN JE3462-HR	**.491**	**470**	**43**	**ON**	**MODERATE NOISE**
HITACHI VK-C350	**.562**	**470**	**43**	**ON**	**CLEAN**
PULNIX TMC-574S	**.600**	**360**	**44**	**ON**	**CLEAN**

** N. S. = Not Selectable*

NEWLY DEVELOPED TEST PARAMETERS

The camera test parameters that were newly developed and tested are white balance, color rendition under commonly used light sources, and low light level color rendition.

White Balance

Color temperature of a light source is defined as the absolute temperature of a blackbody radiator having a chromaticity equal to that of a light source. For example, a commonly used house light bulb (incandescent) has a color temperature of approximately 3200 Kelvin and distributes a reddish light. High pressure sodium's color temperature is around 2100 Kelvin and distributes light that is more saturated by red. On the other hand, fluorescent cool white has a color temperature of 4050 Kelvin and provides close to a preferred white light.

If a color camera used in a CCTV (closed circuit television) system is not white balanced a scene viewed on a properly adjusted monitor will have an overall tint that appears the same color as the illuminating source. The tint can cause objects' colors to appear different than if viewed under a white illuminating source. Most color cameras incorporate circuitry that permits them to white balance and most manufacturers refer to these cameras as auto white balancing. This can be quite misleading because with some cameras the process is not completely automatic. Some provide a button that has to be pushed to activate the circuitry and sometimes while performing this procedure a white object has to be placed in the camera's full field of view, while others will white balance totally automatically throughout a broad range of color temperatures.

White Balance Test Procedures

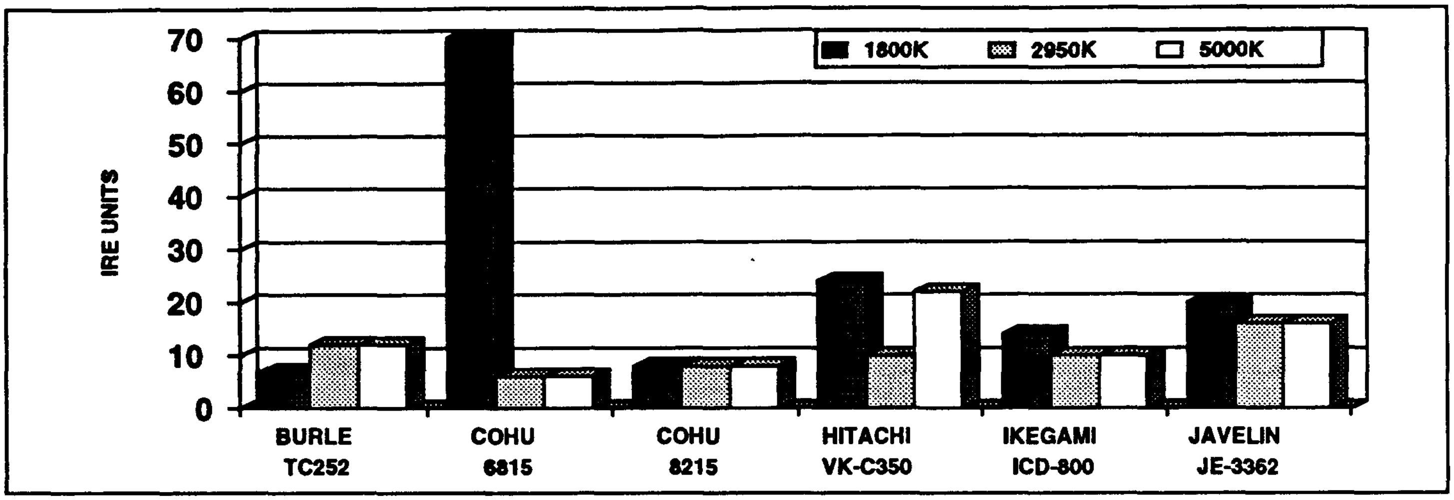
The cameras were tested one at a time using a manual iris lens. A manual iris lens was chosen because of the ease of exchanging the same lens amongst various cameras. The video output of the cameras was attached to the video input of a vector scope and looped through to a color monitor.

The red, green, and blue color squares on a color chart produced by Macbeth Inc. were framed in black. Each camera was setup so that the field of view framed the squares and a portion of the black, making sure nothing else was in the scene. The three colors when viewed by a white balanced camera displays three distinct vectors on the vector scope. However, a camera not properly white balanced displays a fourth vector (spurious vector), and the overall picture tint changes to that of the illuminating source chromaticity.

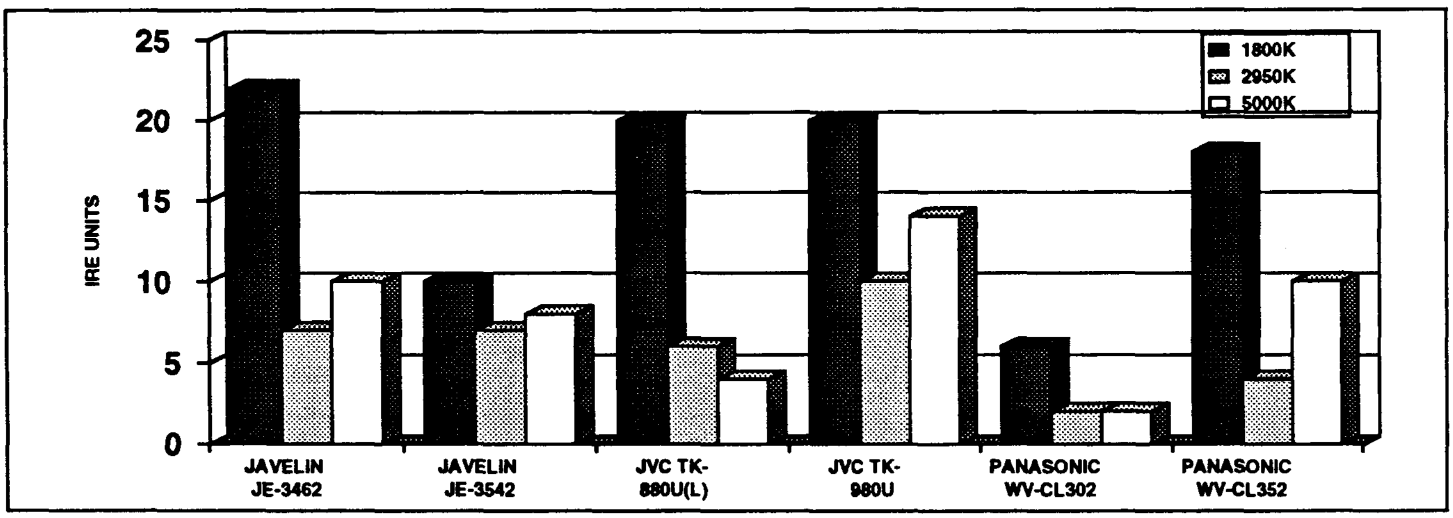
The framed color squares were first illuminated by two incandescent lamps with a color temperature of approximately 2950 Kelvin and the aperture of the lens was adjusted so that the peak video signal reached 100 IRE units, and the magnitude of the spurious vector, if any, was measured. The magnitude of this vector gives an indication of the overall picture chromaticity and is indicative to the camera's white balance performance.

These procedures were repeated at 1800 and 5000 Kelvin, the approximate color temperatures of low pressure sodium and fluorescent cool white respectively. Color temperature changing filters were placed in front of the cameras' lens to achieve these temperatures. The following three graphs show the magnitude of the spurious vector produced at the three selected color temperatures, where zero IRE units is the optimum level and indicates that a camera is white balancing perfectly.

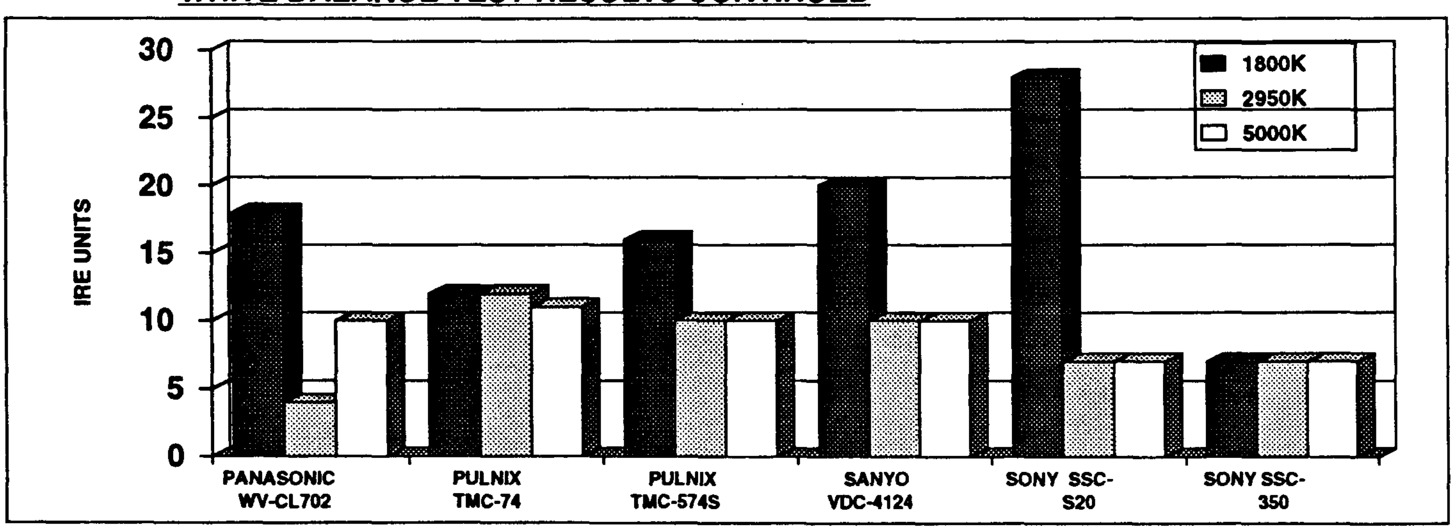
WHITE BALANCE TEST RESULTS



WHITE BALANCE TEST RESULTS CONTINUED



WHITE BALANCE TEST RESULTS CONTINUED



Color Rendition Under Commonly Used Light Sources

What colored objects "color" is perceived under different light sources is an area of concern. For instance, will a red object appear red if it is illuminated by low pressure sodium lighting and the object is viewed through a closed circuit television system? If so, would that same object appear the same hue of red under fluorescent?

The electromagnetic energy reflected from an object causes its perceived color; all other energy is absorbed or transmitted. The dominant wavelength of the energy determines the hue or color, and the amount of reflected energy the brightness.

For instance, if a light source does not emit energy in the wavelength that will be reflected by an illuminated object, then that object will appear gray or black. With that being the case then the spectral power distribution characteristics of an illuminating source are critical. The term "spectral power distribution" characterizes a light source's ability to emit electromagnetic energy at different wavelengths. For example, luminaires that exhibit good spectral power distribution emit electromagnetic energy, representatively evenly, throughout the visible spectrum. These luminaires demonstrate good "color rendering" properties.

An incandescent lamp which demonstrates good color rendering properties was used as a reference against which to compare other commonly used light sources. The other light sources chosen for the color rendition evaluation were fluorescent, high pressure sodium and low pressure sodium.

Test Procedures For Color Rendition Under Various Light Sources

Using the same framed red, green and blue color squares that were used in the white balance test, they were first illuminated by an incandescent light source and a recording was made. Next the chart was recorded while being illuminated separately by the other three light sources.

The recordings were then played through the video input of a vector scope and the signals analyzed. The vector scope displays a discrete vector for each of the three color bars. The hue can be determined from the vector angle and the magnitude represents the amount of color. This procedure provided a means to objectively determine each lamp's color rendering property. The recordings were also viewed on a monitor and subjectively analyzed.

Results of Test For Color Rendition Under Various Light Sources

From knowing the spectral power distribution of the different lamp sources the results were as expected. The fluorescent lamp retains the hue closest to that of the incandescent. Because the high pressure sodium lamp distributes a significant amount of energy in the wavelength of the color bars, the hues also very closely matched that of the incandescent lamp, however the amount of color was less. Because of the lack of energy emitted in the wavelengths that would be reflected by the color bars, the low pressure sodium caused them to appear from grey to near black.

Low Light level Color Rendition

There was a desire to determine at what low light level "colors" would no longer be discernable, so the following test was devised.

Low light Level Color Rendition Test Setup Procedures

Using the optoliner a camera was attached to view a color bar chart. The illuminating source inside the optoliner was set to a color temperature of 2850 Kelvin. At this color temperature the illumination provided is more than enough for the camera to produce a full video signal (100 IRE units peak to peak). Combinations of neutral density filters were placed between the light source and the camera lens to reduce the amount of light reaching the faceplate of the lens. The intent was to discover at what minimum light level the color bars' "color" would no longer be discernable.

Low light Level Color Rendition Results

The low light level color rendition test showed that the picture degrades to a point where it is no longer usable before the color bars' "color" becomes indistinguishable. The picture becomes noisy which causes resolution loss.

SUMMARY

The initial laboratory evaluation was conducted on eighteen solid-state color video cameras by traditional test methods for sensitivity, resolution, the signal-to-noise ratio, and intrascene dynamic range. All eighteen were tested by newly developed test procedures for white balance, color rendition under different light sources, and low light level color rendition.

This evaluation concludes that monochrome cameras continue to perform at higher levels than color cameras. However, color camera technology is rapidly improving ,and with a growing interest in the identification function of security video systems, their consideration is justified.