APPLYING VIDEO TECHNOLOGY TO COLOR MEASUREMENT FOR THE GRAPHIC ARTS INDUSTRY

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Abstract

Video cameras are proliferating in the graphic arts industry for various inspection and control functions. When this technology is used for color measurement, unexpected sources of noise will become evident which will degrade measurement accuracy.

This paper will propose a threshold for acceptable measurement accuracy given a possible color control application. Based on this threshold, measurement variation with respect to time, position and neighborhood will be explored. Tests will be introduced to identify these noise sources without the use of sophisticated lab equipment. Recommendations will be provided to improve the overall system performance.

1. Introduction

Color reproduction quality is a critical concern to the printer and advertiser as well as the press manufacturer. The conventional method used to maintain color consistency is through the use of a densitometer or other devices on uniform targets. Evidence, however, has shown that a well-maintained target does not necessarily guarantee a perfect color reproduction because uncontrollable press and material variations exist. For this reason, an attempt has been made to measure color directly on the printed image. Video cameras have received more attention as a measurement device for this purpose.

The chief advantage of using a video camera is that simultaneous measurements can be taken over a large area. Recent technology improvements in measurement accuracy and pixel resolution have enabled video cameras to be used in color measurement applications. In contrast with the video camera, a densitometer or other point measurement device requires too many individual measurements to obtain information from the same area. Practically this cannot be done in a reasonable period of time.

One disadvantage of using a video camera is that most commercially available cameras are designed for television applications. Currently no viewing geometry or spectral response definition exists for a video camera and its measurement environment in the graphic art industry. This implies less agreement among instruments and no link to a standard color space. In spite of

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this drawback, cameras can still be used in many applications where relative color comparisons are involved. In these applications, the goal is to maintain color consistency. Therefore, the user is more concerned with the measurement repeatability rather than the relation to a standard.

The measurement repeatability of a video system is dependent on the camera, light source, optics, electronics, and viewing geometry as well as the environment in which measurements are taken. In the following sections, tests will be introduced to quantify measurement variations with respect to time, position and neighborhood. These tests are easy to configure and can be performed without the use of sophisticated lab equipment.

Tests of a video system will show that measurement values change under the most controlled situations. The acceptability of these variations depends on the given application. For discussion purposes, a straw man performance standard will be introduced first. Observed measurement variations can then be evaluated and compared to this standard.

2. Straw Man Performance Standard

A straw man performance standard for a web offset color control application will be developed from industry standards regarding acceptable print tolerances. The tolerance suggested by these standards will then be converted to units that can be correlated to camera units of measurement.

Quality requirements for a web offset printing application are described in the SNAP (Specification for Non-Heat Advertising Printing) and SWOP (Specification for Web Offset Publications) specifications. In the SNAP specification, the solid ink density tolerance is specified as ±0.05 from a reference value. For example, a wet black ink density is specified as 1.10 with a tolerance of ±0.05. The SWOP specification uses a Hi-Lo reference to define the acceptability of the print. The printer is allowed to have a tolerance equal to the difference between the Hi and Lo reference. This difference can be represented by a nominal density value of 0.14 from the Lo reference. Tables 2.1 and 2.2 show SNAP and SWOP specification densities and a conversion to percentage of reflectance. The SWOP density data listed in table 2.2 was measured from an actual reference.

	Density (% Reflectance)			
	Reference	Upper Limit	Lower Limit	Deviation
Cyan	0.95(11.2)	1.00(10.0)	0.90(12.6)	0.05(1.3)
Magenta	0.95(11.2)	1.00(10.0)	0.90(12.6)	0.05(1.3)
Yellow	0.90(12.6)	0.95(11.2)	0.85(14.1)	0.05(1.45)
Black	1.10(7.9)	1.15(7.1)	1.05(8.9)	0.05(0.9)

Table 2.1: SNAP Wet Density and Reflectance

	Density (% Reflectance)			
	Reference	Upper Limit	Lower Limit	Deviation
Cyan	1.22(6.0)	1.35(4.5)	1.09(8.1)	0.13(1.8)
Magenta	1.34(4.6)	1.49(3.2)	1.19(6.5)	0.15(1.65)
Yellow	0.96(11.0)	1.08(8.3)	0.84(14.5)	0.12(3.1)
Black	1.50(3.2)	1.69(2.0)	1.31(4.9)	0.19(1.45)

Table 2.2: SWOP Density and Reflectance

From tables 2.1 and 2.2, it can be seen that a one or two percent change in reflectance determines an in or out of tolerance copy. This suggests that noise in the range of one or two percent of the full measurement scale may have an adverse impact on our application. This percentage of noise can be represented as pixel values in the range of two to four in an eight-bit measurement system. For our application, we will suggest that measurement variations should be limited to ±2 out of 256 possible values. Although other applications may require different tolerances on noise, the tests described in this paper are related to the range of ±2 for discussion purposes.

3. Testing Configuration

Having determined the general magnitude of performance required, it must be determined if noise exists in the camera and imaging system to such an extent as to compromise measurement accuracy. This requires that a viewing area and frame grabbing hardware be configured for the tests. The tests described in this paper have been performed predominately under one test environment, except where noted. The environment is an enclosed light booth containing a set of halogen lamps filtered to a standard daylight D50 source, an analog color camera, a frame grabber, and hardware to process and view the image. Each single color image (red, green, blue) has a total of 304,640 pixels in a 640 (H) by 476 (V) format. Tests are performed on color channels individually and so references to "camera" will generally imply one camera channel. The distance from the wall of the booth to the camera viewing area was sufficiently large so as not to affect the illumination of the target. The equipment has power applied for a sufficiently long period of time prior to the test to minimize component drift.

4. Time Dependent Noise Measurements

With the viewing environment configured, testing can begin that will quantify noise that has a time dependency. This type of noise is characterized by measurement value fluctuations over time.

Value fluctuations can be measured by capturing and comparing a series of images. Images can be acquired over a long period of time to observe system drift or over a short time to identify short-term variations. Since drift variances are related to the specific application and the characteristics of the hardware, only the short-term variations will be addressed here.

When two images are captured in rapid succession, they may be compared by subtraction. The subtraction process is accomplished by subtracting corresponding pixels in two images while constructing a third image with the result. A signed subtraction is used such that one minus two yields minus one which is represented by 255. Information about the character and magnitude of the noise can be obtained from the resulting image by observation and the collection of statistics.

Our initial test is performed by placing a uniform grey paper in the entire field of view of the camera. The lighting and lens are then adjusted so that all pixel values are between 200 and 240, on a scale of 256. This will ensure a sufficiently high value without saturation in any pixel. Two images of the grey paper may then be digitized, subtracted and displayed on a monitor. With identical images, the result will be zero for every pixel. This will be seen as a black image on the monitor. Typically the two captured images will be different when noise exists. This will cause the positive and negative subtraction results to be shown as dark and light areas on the screen. The result of two subtracted images is shown in figure 4.1.

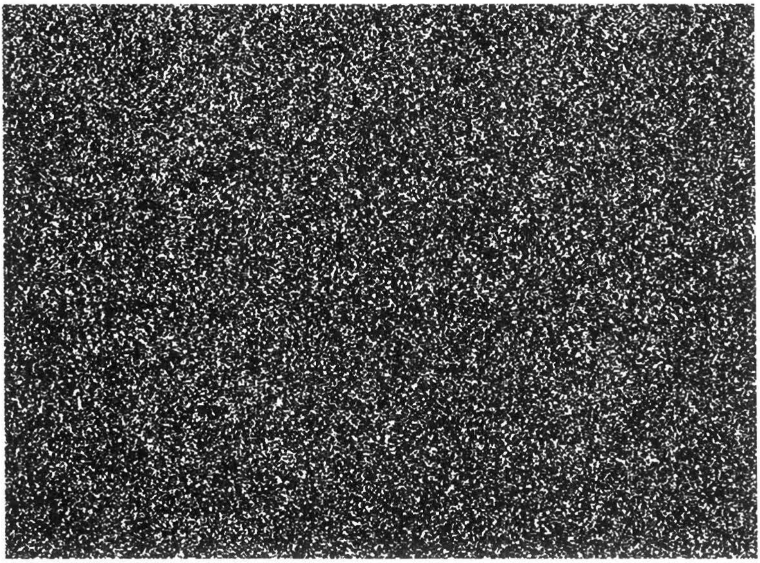

Figure 4.1: Random Noise

The first step in analyzing the subtraction result is an examination of the image for features. Some of these images will show features such as lines or patterns while others will show randomly distributed light and dark areas. When a deeper understanding of the noise is required, the mean and standard deviation can be taken over sections of the image. Once this is accomplished, the test should be repeated several times to determine the stability of the result.

The subtraction result in figure 4.1 does not show a pattern in the black and white areas over the image area. Our immediate conclusion following visual inspection is that noise exists and that it appears to be random (featureless). The small value differences in the black or white spots on the image are generally not discernible to the naked eye when viewing the resultant image. For this reason a statistical analysis must be performed that includes finding the mean, standard deviation and histogram of the whole and partial image. Figure 4.2 is the histogram of the subtraction result found in figure 4.1 image. Our difference image has a peak value of 15, a mean of 0.17 and a standard deviation of 2.5. The randomness of the noise is generally favorable, but the peak noise value is considerably above our goal. In fact, more than thirty percent of the pixels fall outside our tolerance of ± 2.

Another manufacturer's board was tested using the same camera and capture environment to see if the noise level would be similar. A histogram comparison of the first and second manufacturers' boards are shown in figure 4.3. From this figure, it is easily seen that the second manufacturer's board exhibits much more noise than the first. The second board has an absolute peak value of 80, a means of 0.15 and a standard deviation of 9.39. The larger standard deviation indicates more pixels will fall outside our goal. Having tested two equipment configurations and both showing more variation than is acceptable, it becomes apparent that a process is needed to reduce the observed noise level. Techniques for reducing the noise level will be provided later in this section. Before that is discussed, we would like to show that other types of time dependent noise exist.

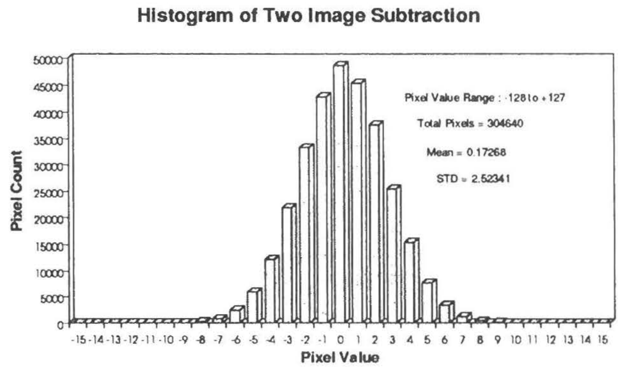

Figure 4.2: Single Board Noise Statistics

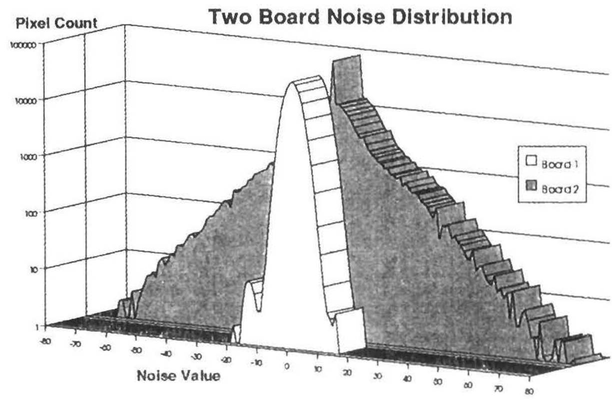

Figure 4.3: Noise of Two Board Manufactures

Some noise exhibits patterns in the subtraction result. Figure 4.4 shows the subtraction result of a third board while still using a uniform grey paper as a target. About ten horizontal lines can be seen in this image which characterizes the noise as a non-random distribution. It appears a signal has modulated the video image. Since other components in our viewing environment were undisturbed, it can be concluded that this component of the noise originates on the frame-grabbing board.

In addition to noise that is constrained to the imaging board, noise can be introduced by the lighting system. The output from a lighting system can be constant, periodically variable, or pulsed. Light output variations can be viewed on an oscilloscope using a simple photodetector. A constant output light source, such as a DC powered halogen lamp, will have a minimal effect on the measured noise. A pulsed light source, such as a xenon flash lamp, may have a different energy output and lighting pattern for each strobe. Periodic sources, such as a fluorescent lamp, can introduce noise that changes the pattern and amplitude. This becomes worse when the frequency of the lamp's power is not an integer multiple of the camera frame rate. For very high frequencies (10khz to 100khz), the effect will be negligible. Figure 4.5 shows the subtraction result when the target is illuminated with fluorescent lighting powered at 60 hertz. The image shows a large dark band on the lower section. When this type of noise occurs, revisions to the lighting system are recommended.

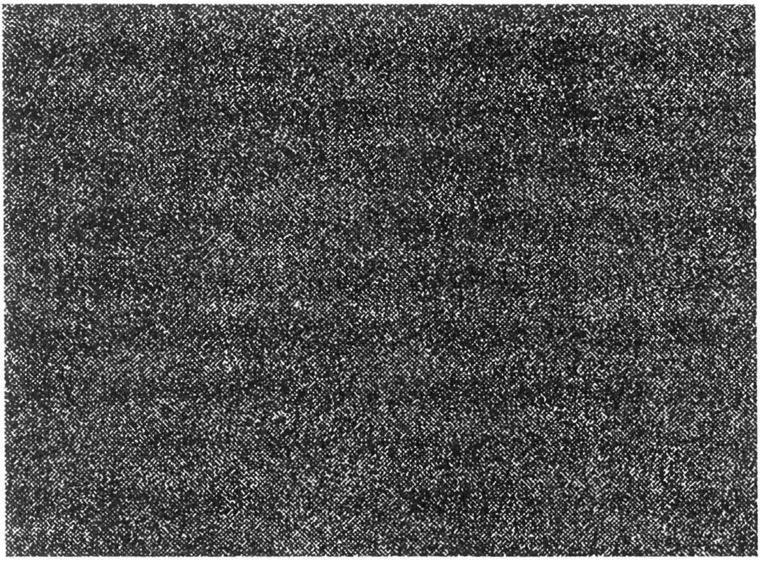

Figure 4.4: On Board Modulation

Time dependent noise can also be generated by a lack of synchronization between the camera and the frame grabber. This type of noise will not be evident with a uniform grey target but can be seen with a high spatial frequency image. This type of image is characterized by sharp edges. For our purposes, we will be especially interested in edges in the vertical and horizontal directions since these correspond to the sweep patterns in the camera. An example of this type of image might be a chess board or repeated horizontal and vertical black lines on white paper. Figure 4.6 is the image we will use for detecting synchronization errors. When two of these images are subtracted, the result is provided as shown in figure 4.7. On inspection, it can be seen that the vertical and horizontal edges are easily identifiable. Horizontal and vertical lines in the subtraction result are indicative of poor vertical or horizontal synchronization between the camera and the imaging board.

When an application requires higher spatial frequency images and this type of noise exists, it is recommended that the camera clock be connected to the digitizer. This should reduce the timing difference between the camera and frame-grabbing clocks. A digital camera with the A/D converter chip close to and synchronized with the imaging sensor may also reduce this type of noise.

The tests so far have shown noise levels higher than that desired in our performance goal. In order to obtain the desired measurement accuracy, noise can be reduced through image processing. Many processing functions exist to accomplish our goal, but we will focus on image averaging. The averaging method can be demonstrated by capturing an image several times and averaging corresponding pixels in them to produce a single image. By increasing the number of images averaged in each group, the noise is reduced as shown in figure 4.8.

# Averaged	1	2	4	8	16	32	64
Mean	0.17	0.07	-0.02	-0.03	-0.06	-0.05	0.06
STD	2.52	1.79	1.31	0.97	0.74	0.60	0.50
# Zero pixels	48,560	67,957	92,724	124,836	161,854	198,171	227,867
% pixels out of ±2	31.9	15.7	4.9	0.68	0.04	0.01	0.002

Table 4.1: Noise Reduction By Image Averaging

Table 4.1 shows the effect on the mean and standard deviation (STD) for a different number of averaged images in each group. The data in this table shows that the standard deviation drops as the number of images averaged increases. This increases the probability of finding pixels with zero or low values which is our goal. Depending on the application, the user can trade off the number of images averaged and the desired performance.

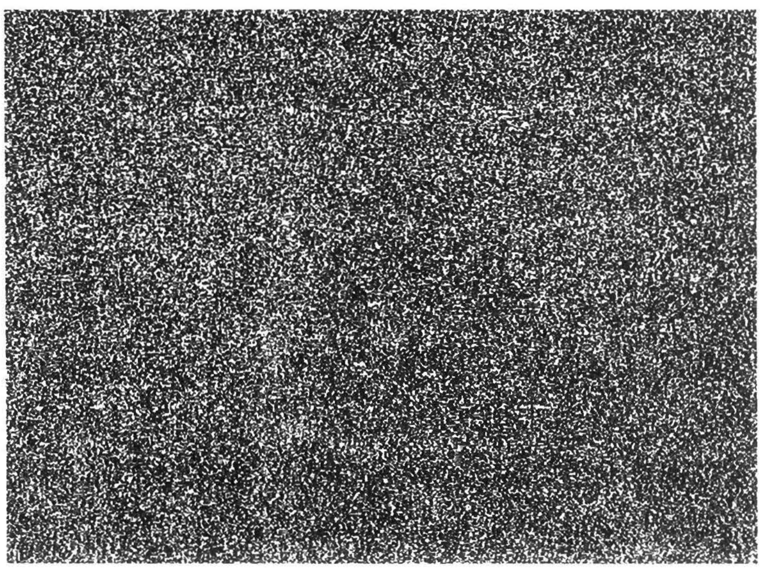

Figure 4.5: Fluorescent Lamp Noise Pattern

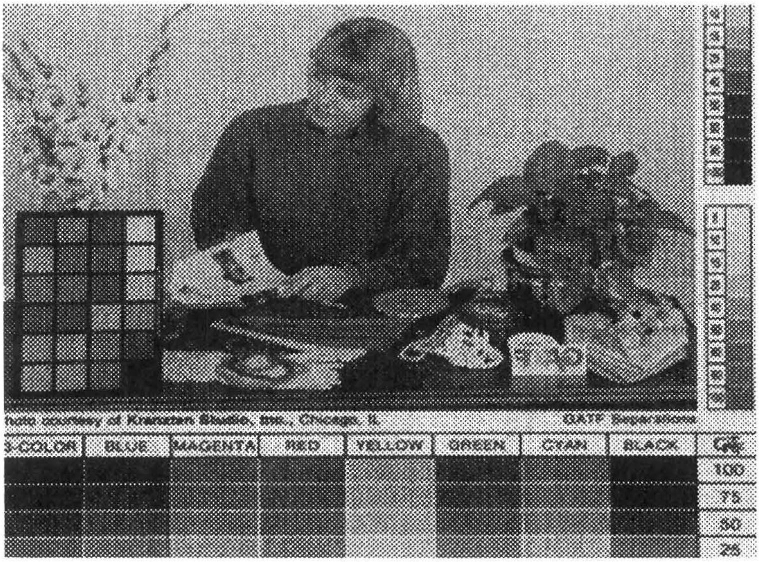

Figure 4.6: High Frequency Image Example

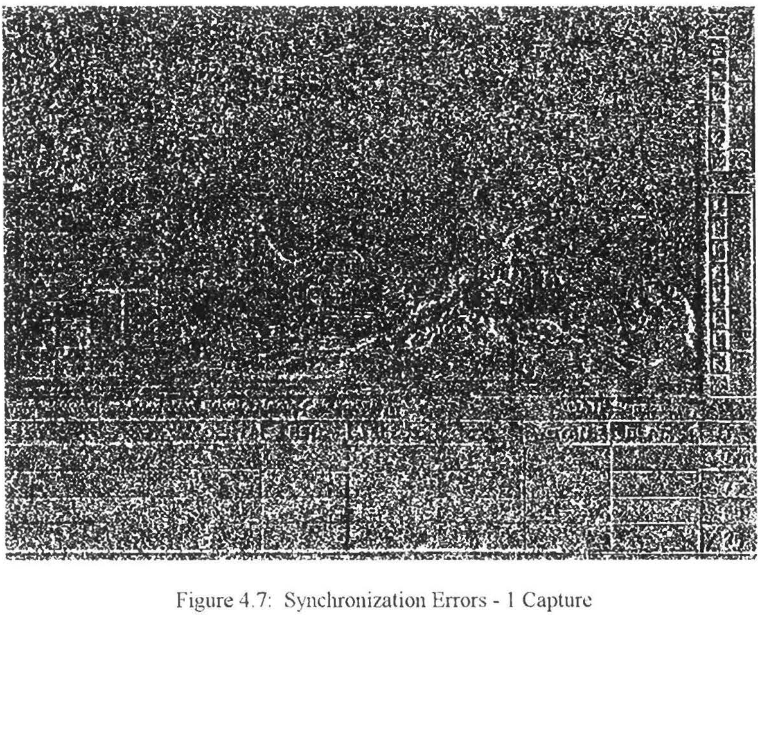

Figure 4.7: Synchronization Errors - 1 Capture

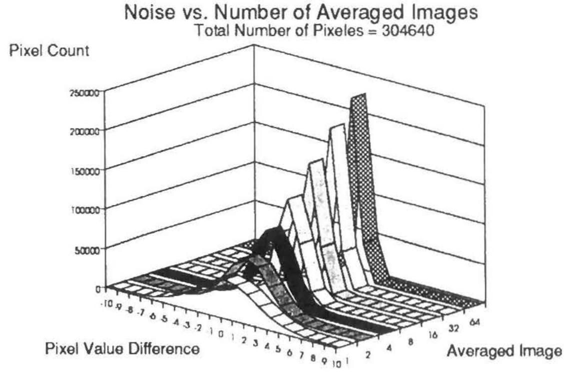

Figure 4.8: Noise Reduction by Image Averaging

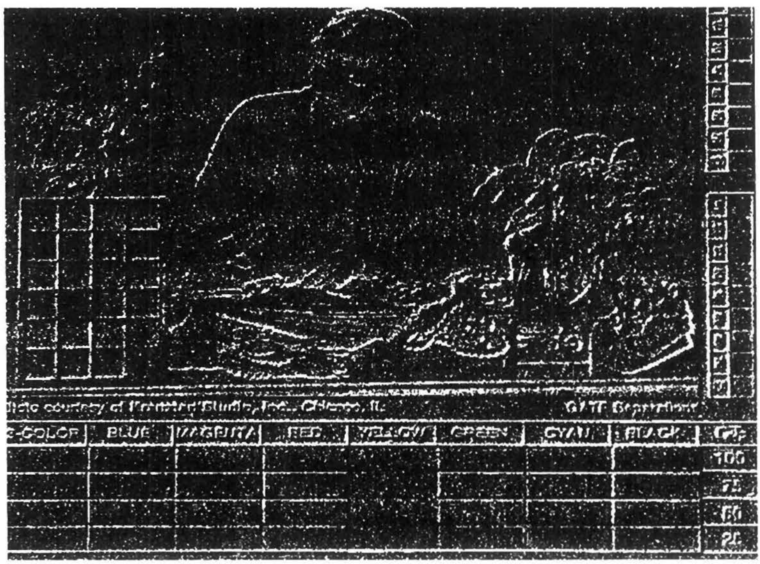

Figure 4.9: Synchronization Errors - 64 Capture

The fact that averaging reduces the overall noise can be used to facilitate finding certain types of difficult to detect noise by making it more visible. For example, synchronization errors were detected through the subtraction of two images as seen in figure 4.7. When 64 images are averaged and then subtracted from another group of 64 averaged images, the overall noise is reduced so that the synchronization errors become more prominent as shown in figure 4.9. Table 4.2 shows the noise reduction between figures 4.7 and 4.9.

Figure	4.7	4.9
Images/Grp.	1	64
Noise Mean	-0.15	0.09
Noise STD	2.55	0.98

Table 4.2: Averaging with High Frequency Images

If the noise mean is near zero, time-dependent noise can be reduced by averaging pixels in a picture segment. This permits a single image to be captured while gaining the benefits of reduced noise. This method is typically used on uniform targets which may be found in some applications.

5. Position Dependent Measurement Variance

In the previous section a test was described to determine the repeatability of a target value while the target remained in the same position and under the same conditions. Once this has been evaluated and constrained to an acceptable level, a second test can be performed that determines the repeatability of measurement for the same target in various positions of the camera field of view.

The test to determine positional measurement repeatability is performed by placing a white target against a black background. The target size should be about one tenth the size of the field of view in either direction. The target measurement is calculated by averaging target pixels to minimize the effect of time-dependent noise. The target is then moved progressively outward from the center of the field of view while measurements are taken. The difference between the measurements represents the measurement variance with respect to position.

An alternative way to perform this test is to capture an image from a uniform target that occupies the full field of view. The comparison of groups of averaged pixels provides the positional measurement variance. A representative image is shown in figure 5.1. Measurement results for the image in figure 5.1 yield a variance of ten percent of the full scale measurement. This is represented as light (higher values) and dark (lower values) areas in the image.

Most of the position-related variance measured is the result of two factors. The first is non-uniform light over the target area. The second factor is the unequal transmittance of light through various portions of the lens. Ideally, the light should be adjusted for uniformity over the target area. This, however, will not produce uniformity as perceived by the camera when the lens has unequal transmittance across the image area. For this reason, the deficiencies in the lens must be addressed first.

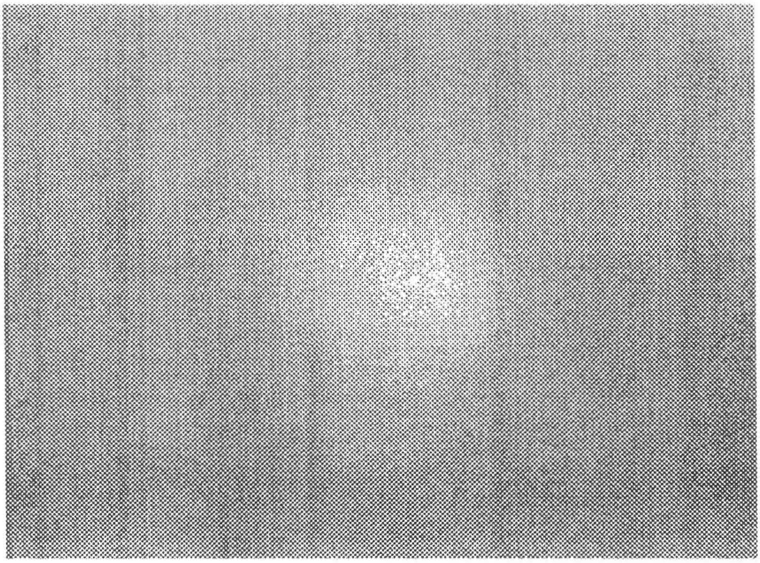

Figure 5.1: Lighting Distribution

Generally the transmittance of a lens decreases from the center to the edge. For this reason, a uniformly illuminated target will not produce uniform illumination on the focal plane of the lens. The relative illumination at the focal plane can be plotted in a chart usually called the relative illumination curve. One such curve is shown in figure 5.2. The curve shows less light is transmitted as the distance from the center of the lens increase. In addition, an iris opening of f1.2 will exhibit more fall-off than an opening of f4.

Less variation in transmitted light may be achieved by choosing a proper lens for the camera. Lenses designed for an imager larger than that used in the camera may provide more uniform light from the center to the corners. For example, if a 2/3-inch imager is used, a lens designed for a 1-inch imager may provide a more uniform lighting characteristic than one specifically made for the 2/3-inch imager.

Once a lens is chosen, the light arrangement may be adjusted to compensate for deficiencies in the lens. The adjustment process can be divided into two tasks. The first task is to eliminate specular reflection and the second is to achieve uniform light across the target as viewed by the camera. It is important to eliminate the specular reflection because a high gloss target can reflect light directly into the camera when the target is placed in a certain spatial relationship to the light and camera. This will significantly increase the targets measured value compared with areas where little specular reflection exists. Specular reflection can be reduced by placing the lamps in positions as shown in figure 5.3.

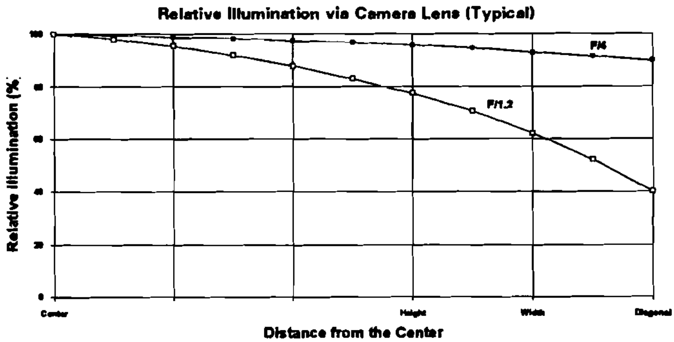

Figure 5.2: Lens Transmittance

Once provision has been made to reduce specular reflection, the lamps should be adjusted to obtain a uniform field as viewed by the camera. This task can be easily accomplished by displaying a live image with color coded intensity values. Table 5.1 shows how single channel camera values might be mapped to different colors.

Measured Pixel Range	Displayed Color	Description
250-255	White	High+
245-249	Beige	High
240-244	Green	Excellent
235-239	Drk. Grn.	Good
230-234	Red	Low
0-229	Blue	Low-

Table 5.1: Image Value Color Mapping Example

With a uniform target in the field of view, the number of lamps and their positions are adjusted to achieve the desired uniformity. In the described color mapping example this would be a green image.

Regardless of the effort expended in adjusting lamps, there may be a limit as to the uniformity achieved. This will depend on the size of the target, number of lamps, lighting angles, ability to adjust individual light intensity, etc. If a practical limit is reached and less measurement variance is desired, the light may be computer compensated to further improve the uniformity. Compensation can be performed on an application image with the aid of a second image. The second image is referred to as a light reference. The reference is a captured image of a uniform target with similar surface properties as that used in the application. The images captured by the application may then be compensated, area by area, by applying a multiplication factor derived from variances in the reference. Other methods, such as that described in Mumzhiu and Bunting (1992), use two references: one black and one white. The application image values are then mapped linearly based on these two references. The methods described can be implemented on an entire image as well as a pixel by pixel basis depending on the computational power available.

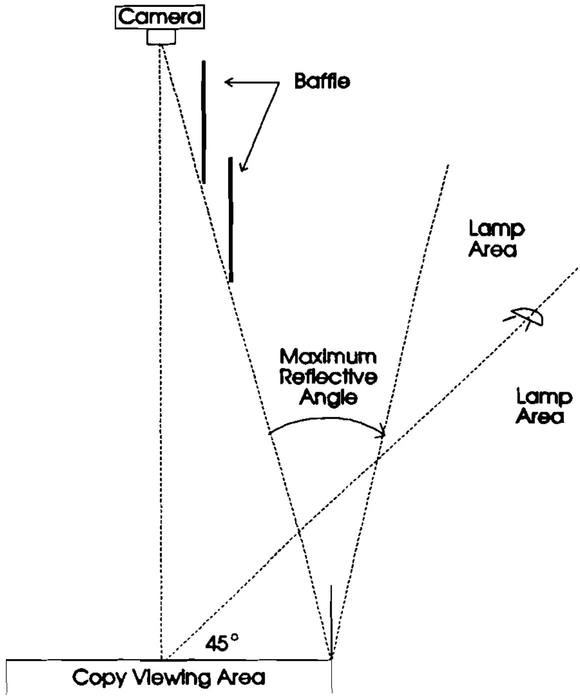

Figure 5.3: Lamp Placement Guide

Due to the cameras large field of view, it may be impossible to achieve zero positional variation for any given surface. When the specular reflection is eliminated and light compensation is employed, the variation remaining after prudent adjustment of the lamps is generally acceptable in applications where relative color comparisons are involved.

6. Neighborhood Measurement Variance

In addition to time and position dependent measurement variances, a third source of noise is dependent on the neighborhood. The presence of this noise is evident when a pixel value changes as neighboring pixels are changed. It is desired that the measurement of any point in the image area to be independent of the surrounding image content. This, however is not always possible because of limitations in the optical system and the electronics. A test, introduced in this section, can be used to determine coupling between a given pixel and neighboring pixels.

Dependence on other pixels can be found by measuring a target as different backgrounds are applied. This is accomplished by first placing a uniform grey target in the field of view of the camera as shown in figure 6.1. A hole is cut in a piece of white paper and the white paper is placed over the grey. The hole is about one-tenth the camera field of view in each direction. With the setup complete, the iris is then adjusted so that the pixel values are as high as possible without saturation. A measurement is recorded by averaging the pixel values over the grey target area. This measurement will be denoted as W1. A second measurement is taken of the same grey target but with a black paper background in place. This measurement value will be called W2. In an ideal system, W1 should be equal to W2. In non-ideal systems, W1 will be different from W2. The difference between W1 and W2 represents the measurement variance caused by pixel coupling. Table 6.1 shows our test results which have difference values in a range of five to thirty-two, depending on the camera and optics.

Camera	W1	W2	W1-W2
#1	180	175	5
#2	182	150	32

Table 6.1: Neighborhood Effect

The neighborhood effect is usually caused by two factors: internal reflections in the camera optical system and voltage instability in the electronics. The reflections can occur at any glass to air surface and at the surface of the CCD. Glass can be found in the lens as well as the camera head. Reflections can be reduced to a more tolerable level by applying an anti-reflection (AR) coating to the glass surfaces. Each AR coating has its own working wavelength range. Outside this range, the effect of this coating will be reduced. Generally, the severity of reflections increases as the reflecting surface approaches the CCD.

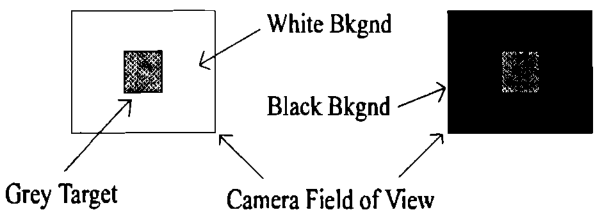

Figure 6.1: Neighborhood Test Setup

Regardless of whether the proper coating has been applied, a portion of the reflected light will strike the wall of the lens or camera housing. This will not generally cause a problem if the wall can absorb the energy. Energy that is not absorbed by the housing may ultimately strike the CCD (possibly for the second time) causing the coupling discussed.

The camera electronics may also cause a coupling affect. An enabled AGC circuit, an inadequate coupling capacitor, or an unstable black level may increase the coupling affect.

If the test for neighborhood dependence yields a high value, such as that shown for camera number two in table 6.1, the coupling may be further described with additional testing. This additional testing is done by moving a black object against a white background. The black object can be from ten to twenty-five percent of the image size in each direction. Display lookup tables may be set to accentuate value changes in non-target pixels. Figure 6.2 shows the uniform white field as viewed with display output thresholds and before the black object is introduced. The dark spots seen in the figure are caused by surface roughness and are about 2 pixel values darker than the remaining image. It can be seen that the pattern is random. A black object is then moved to the lower left corner of the image as shown in figure 6.3. A shadow can be seen in the upper right corner. As the black object is moved from the lower left to the lower right, the shadow moves to the left as shown in figures 6.4 and 6.5. Pixel coupling is described by the relation between the shadow and the target.

From the series of figures, we assume light is reflected from the area to be occupied by the black object to the area of the shadow. Placement of the black object limits this light and reduces the energy reflected. The absence of this reflected light causes the observed shadow. This phenomenon is mostly caused by the optical system of the camera.

Coupling effects can be reduced by applying any or all of the following suggestions.

- Proper coating of the glass to air surfaces
- Elimination of reflective surfaces close to the CCD.
- Ensure the lens and camera housings are painted black.
- Ensure sufficient coupling capacitance for analog cameras.
  (Use a digital camera interface where applicable.)
- Disable the camera AGC.
- Disable the camera auto-iris.

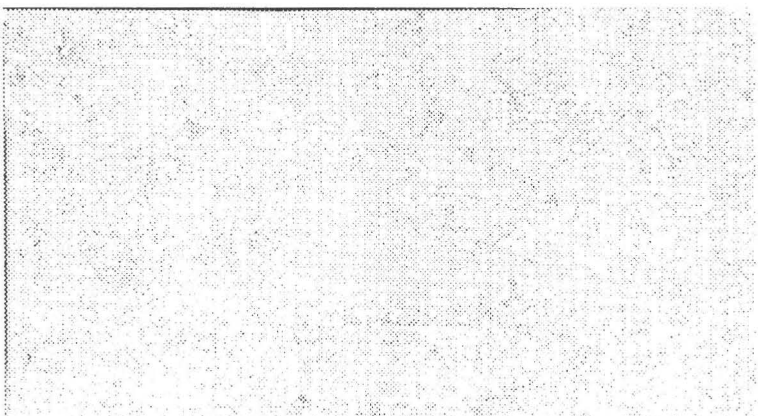

Figure 6.2: Neighborhood Measurement White Field

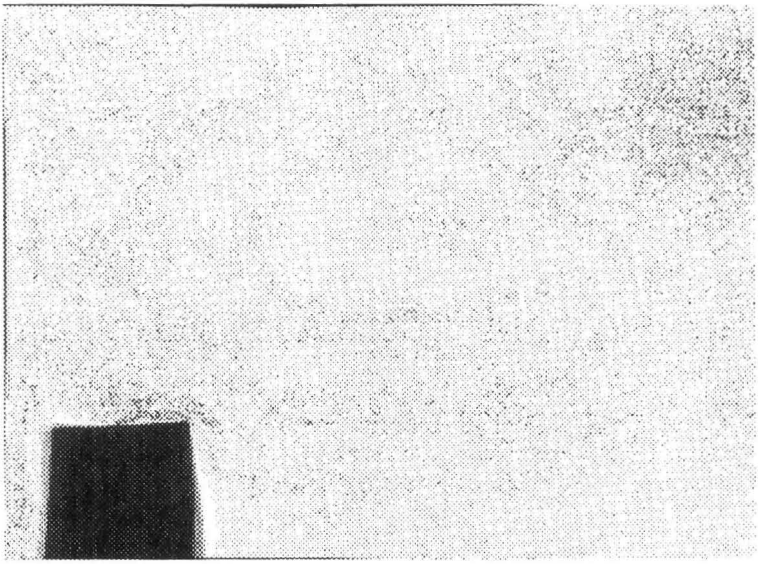

Figure 6.3: Neighborhood - Lower Left

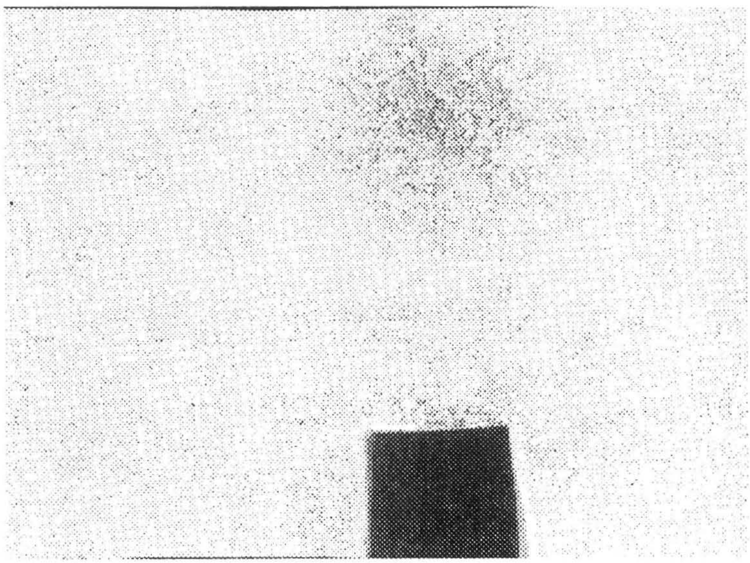

Figure 6.4: Neighborhood - Center

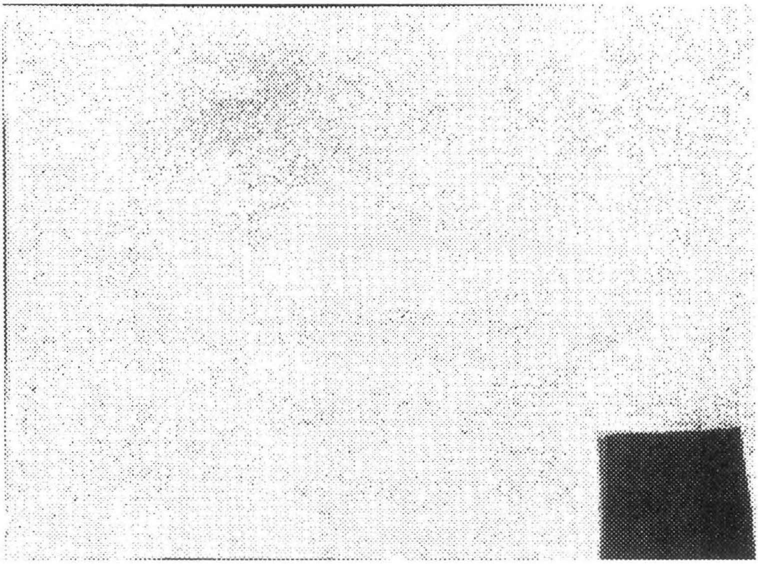

Figure 6.5: Neighborhood - Right

7. Summary

Color measurement applications require higher accuracy than that typically found in other video applications. We have explored three types of noise that can degrade the performance of the video system. Those applying video to color applications can develop a performance standard and identify, through simple tests, the magnitude of their system noise. Acceptable levels of performance may then be achieved by careful hardware selection and sufficient image processing.

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