The Development of a Color Reference Chart, New Color Test Pattern, and Instrumentation for Television Camera Calibration

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Introduction

Today's camera professional requires unheralded flexibility in the capturing of color television images both in the studio and on location. This poses serious challenges to the user to assure that image and color quality can be maintained over time and possibly between a number of cameras. When numerous cameras are used in a given locale, the ability to seamlessly transition from one camera to another, one perspective to another, with no noticeable change in color quality is imperative. It is essential to understand the numerous elements that contribute to and effect television color reproduction. The review of these concepts will be brief and readers are encouraged to consult additional texts in this area[1, 2] for more in-depth review.

To obtain colorimetric calibration of a television camera, the measurement of a Color Reference Chart is appropriate and can provide a meaningful analysis of camera response as well as insight on the necessary means of adjustment to achieve desired effects. A similar type of Color Test Pattern can be useful in evaluating color reproduction of a complete television system. The parallel development of both a Color Reference Chart and Color Test Pattern, to facilitate the colorimetric calibration of color television cameras will be discussed. Both are currently under review by the Society of Motion Picture Television Engineers for adoption as U.S. television standards.

In addition, a television test and measurement product implementation of such camera calibration technology will also be reviewed.

Considerations of the Television Application

To assess a video camera's color reproduction capability, it must be evaluated independent of the other components within the television system. Color television systems are inherently non-colorimetric and incorporate certain types of system "distortions" to optimize other aspects of picture quality. It is, however, possible to determine the absolute colorimetric reproduction capability of various pieces of a system, provided the appropriate corrections are made.

There are numerous types of television cameras available that make different assumptions about the colorimetry of the Green, Blue and Red reference primaries of a given broadcasting standards (e.g. EBU (PAL) or NTSC). In general, a broadcast camera is engineered and optimized to capture images in the studio environment. Cameras are designed to image colors under "typical" studio illumination which is considered to be 3200K but in practice, is generally closer to 3100K. Television encoding standards, however, are based on a system white reference of CIE D65. In addition, the raw sensitivities of the CCD sensors within the camera do not resemble the "taking primaries" defined by television encoding standards. Cameras are built to compensate for these variations and do so using a hardware camera *matrix*. The overall result is that when the matrix is enabled, the camera input is from an original lit under the studio illuminant, and the camera outputs RGB values relative to the appropriate encoding standard *as if the original were illuminated using the television* ***system*** *white point of D65*.

By design, the camera has built into it a gamma compensation that is designed to yield an optimal overall system gamma when it (the camera) is coupled into a complete television system. This creates colorimetric distortion which must be corrected out.

Color Reference Chart

Over the years, the television industry has relied on the use of a variety of test charts for the characterization and adjustment of different aspects of the television system. For example, the various multiburst charts utilized for measuring frequency response and aliasing as well as the standard registration charts used to measure both geometric distortions and registration have been utilized for many years to quantify the performance of television cameras.

During television's evolution as a color medium, various methods were utilized to test color rendition, most of which have fallen out of use for one reason or another. In practice, many users relied simply on proper white balancing of the camera or proper adjustment of camera registration and gamma assuming appropriate color rendition would result. n more recent times, the Macbeth ColorChecker™ Color Rendition Chart has evolved into a de facto standard in the television industry for improving the process of accurate color reproduction. This Chart is made up of 24 sample colors whose colorimetric designations are distributed throughout standard color television gamuts.The first two rows consist of colors that are designed to simulate the color appearance of natural objects. The third row consists of colors that represent subtractive primaries (cyan, magenta, and yellow) as well as the binary combinations of these colors (red, green, and blue). The last row consists of a 6 step neutral gray scale.

The ColorChecker is a practical tool due to its ease of availability and relatively low cost, particularly when one considers the need to calibrate cameras at remote locations under a variety of conditions that are not necessarily favorable to long-term maintenance of material standards (e.g. studio remote van).

There have been numerous complaints in the television industry that the ColorChecker was not useful since some colors were out of gamut for the various standard and proposed television gamuts (i.e. NTSC, PAL, CCIR 709). One serious contributing factor was that the colorimetry being used to define the chart colors was based on previously published data for the ColorChecker samples which was obtained using a color measurement technique not applicable to a television application.[3] As a result, use of this original data in a television scenario will result in ColorChecker renditions that vary noticeably from actual chart appearance. To improve utility, a restandardization of the Macbeth ColorChecker was required to devise a set of nominal tristimulus aim points for each of the standard's 24 colors under conditions appropriate for the most common television scenarios.

Spectral Measurement

Originally, full spectral data for each Color Checker sample was determined spectrophotometrically at 10 nm intervals using a General Electric Recording Spectrophotometer (GERS) with a d/6 diffuse sphere geometry. The colorimetry data was computed assuming CIE Illuminant C and is furnished with each purchased chart. As previously mentioned, both the measurement geometry and assumed illuminant are incorrect for a television application. It was essential to utilize a 45/0 measurement geometry since it is most like that of the studio viewing condition under which a ColorChecker chart would be imaged by a camera.

Representative ColorChecker colors were obtained from archived samples kept in dark storage at Macbeth, Inc., New Windsor, New York. Two samples each from six yearly production runs between 1986-1992 were used for the evaluation. Statistical analysis was used to check for errant data and the mean of each reflectance was calculated.[4] The spectrophotometric and colorimetric data for the chart will be published elsewhere.[5]

Remeasurements of the ColorChecker samples were made using a Macbeth CC-545 portable spectrophotometer with 45/0 geometry which conforms to standard specifications.[6,7] This instrument has a (triangular) bandpass of 5 nm. Reflectance data was obtained in the spectral range of 380 nm to 780 nm at 5 nm intervals according to CIE prescribed methods.[8] Colorimetric specifications for sample aim-points of each chart sample were obtained via tristimulus integration assuming the CIE 1931 (2°) Standard Observer and CIE D65.

The ColorChecker combined with this new, more appropriate color data can now be used to correctly assess the colorimetric accuracy of a television camera. This newly determined colorimetric data indicates that all 24 samples of the ColorChecker are capable of being rendered in the NTSC Television System (which assumes a D65 correlated color temperature forthe system reference white). If one assumes the EBU or CCIR 709 encoding parameters, the Cyan ColorChecker sample is out of gamut. (Requiring a negative voltage in the Red channel.)

Color Test Pattern

It is also possible to utilize the newly determined ColorChecker data to generate a color test pattern to assess television system color reproduction via direct display on a broadcast studio monitor. Generation of the chart is straightforward.

The newly determined CIE XYZ tristimulus values for each chart color must be converted into appropriate RGB values for display. Conversions are made using a 3×3 linear transformation matrix. The required RGB intensity data is derived separately for each encoding standard due to:

- Colorimetry differences in the encoding standard system primaries, and

- Different white and black level considerations in the signal domain (e.g. in NTSC, white is at 740mV (100 IRE) while black is at 7.5mV).

Gamma correction is then applied according to standard requirements or as dictated by desired artistic effects.

The physical dimensions of the Color Reference Chart are, nominally, 13" in width and 9" in height. In order to make depiction of a test pattern representation of the chart straightforward with respect to the standard television aspect ratio of 4:3, it is necessary to increase the top and bottom borders as measured on an actual Macbeth ColorChecker by 3/8" each. This is required since geometric designations of the chart color samples and spaces are expressed in terms of percent picture height and percent picture width as shown in Figure 1. This will retain relative sample sizes and layout of the chart which is essential in any representation. For applications such as television camera color calibration, where an actual chart is utilized, no physical change need be made to any given Color Reference Chart but the user should make sure that the center of each color sample is being imaged/captured for highest accuracy.

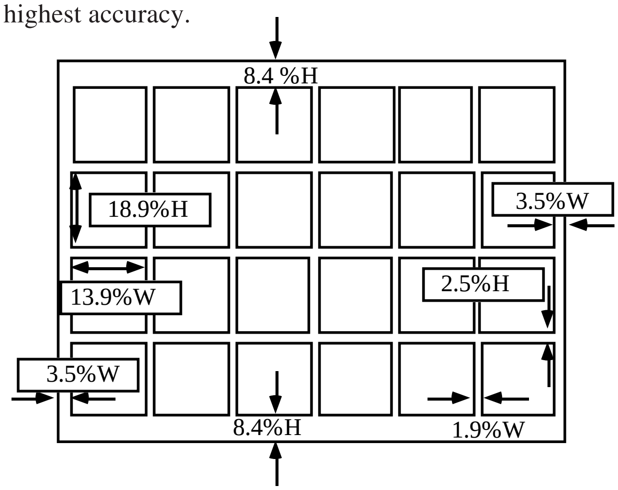

Figure 1. Color Reference Chart elements expressed in terms of percent picture height and percent picture width.

Product Implementation

A relatively new implementation of the colorimetric remeasurement data for the Macbeth ColorChecker can be found in the state-of-the-art VM700A Video Mea-sure-ment Set Option 21 Camera Measurement product manufactured by Tektronix, Inc. This product is designed to assist the television camera professional in the processes of acceptance testing, routine maintenance and operational adjustment by providing a comprehensive and fully automated testing package. In addition to Colorimetry, there are modules for testing a variety of other camera parameters including; CCD Defects, Fixed Pattern Noise, Gamma, Geometry and Registration, to name a few. For the purpose of this discussion, only the Colorimetry functionality will be discussed.

The sets of standardized data obtained for the Color Reference Chart are stored in the VM700A in the form of CIELUV and u'v' coordinates. Prior to colorimetric measurements, the camera gamma is determined using the Gamma module. Once determined, this data is stored for use by the Colorimetry module at the appropriate time.

When instrument set-up commences, the user selects an assumed phosphor set and illuminant. The data associated with these parameters dictate the appropriate transformation matrix for conversion between input RGB and CIEXYZ. The first measurement that is taken is for the Chart white sample. In practice, the TiO_2-based chart white is used for calibration purposes. However, the colorimetry of the ColorChecker samples is determined using a barium sulfate ($BaSO_4$) plaque calibration standard corrected to the perfect reflecting diffuser. The user follows a custom white balance procedure to correct for this difference. When colorimetry measurements commence, the raw RGB data for each sample is acquired by the camera and processed through the built-in matrix. This data is input into the VM700A and the appropriate inverse function is applied in order to eliminate the effects of a non-colorimetric gamma. At this point, the appropriate conversion matrix is used to translate all adjusted RGB voltages to CIE XYZ. From there, CIELUV color calculations are made. Subsequently, these values are compared to stored aim-point values for the Reference Chart, CIELUV Color Difference calculations are performed and data, along with a graph of sample chromaticity values is output directly to the display user for camera evaluation purposes. A secondary display can be utilized during continuous signal acquisition allowing the user to monitor the effects of camera adjustment.

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