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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

**THE RELATIONSHIP BETWEEN DIGITAL
AND COLORIMETRIC DATA FOR
COMPUTER-CONTROLLED CRT DISPLAYS**

CIE 122-1996

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Descriptor: Colorimetry
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This Technical Report has been prepared by CIE Technical Committee 2-26 of Division 2 "Physical measurement of light and radiation" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

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Foreword

The following members of TC 2-26 Measurement of Colour Self-Luminous Displays took part in the preparation of this technical report. TC 2-26 comes under CIE Division 2 "Physical Measurement of Light and Radiation".

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THE RELATIONSHIP BETWEEN DIGITAL AND COLORIMETRIC DATA FOR COMPUTER-CONTROLLED CRT DISPLAYS

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THE RELATIONSHIP BETWEEN DIGITAL AND COLORIMETRIC DATA FOR COMPUTER-CONTROLLED CRT DISPLAYS

Summary

This technical report describes instrumentation and accuracy requirements appropriate for the measurement of the spectral and colorimetric characteristics of computer-controlled CRT displays. The relationship between digital and both spectral and colorimetric data is described based on the generic signal processing and electronics of this technology. A practical methodology is described to characterise the colorimetric properties of a computer-controlled CRT. A worked example supplements the described methodology.

CORRESPONDANCE ENTRE LES SIGNAUX NUMERIQUES ET LES GRANDEURS COLORIMETRIQUES ASSOCIEES POUR LES ECRANS CATHODIQUES A CONTROLE NUMERIQUE

Résumé

Ce rapport technique spécifie les matériels nécessaires et les exigences en matière de précision pour la mesure des caractéristiques spectrales et colorimétriques des écrans cathodiques à contrôle numérique. Les relations entre les données numériques et les données à la fois spectrales et colorimétriques sont décrites. Elles s'appuient sur le traitement des signaux et l'électronique de cette technologie. Une méthode pratique y est exposée; elle permet de caractériser les propriétés colorimétriques d'un écran cathodique sous contrôle numérique. Un exemple pratique illustre la méthode décrite.

DER ZUSAMMENHANG ZWISCHEN DIGITALEN UND FARBMETRISCHEN DATEN FÜR COMPUTERGESTEUERTE KATHODENSTRAHLRÖHREN- ANZEIGEN (CRT-DISPLAYS)

Zusammenfassung

Dieser technische Bericht beschreibt instrumentelle Voraussetzungen und Genauigkeitsanforderungen, die für die Messung der spektralen und farbmétrischen Eigenschaften von computergesteuerten Kathodenstrahlröhren-Anzeigen angemessen sind. Die Beziehung zwischen den digitalen Daten einerseits und den spektralen sowie farbmétrischen Daten andererseits wird auf der Basis der typischen Signalverarbeitung und Elektronik dieser Technologie beschrieben. Eine praktische Methodik, die farbmétrischen Eigenschaften einer computergesteuerten Kathodenstrahlröhren-Anzeige zu kennzeichnen, wird beschrieben. Ein praktisches Beispiel ergänzt die beschriebene Methodik.

1. INTRODUCTION

1.1 Overview

Colour cathode-ray tubes (CRTs), also referred to as self-luminous displays, are a member of the class of visual display units (VDUs) that include liquid crystal, light-emitting diode, plasma and light valves. CRTs are the dominant technology in this century being used extensively in both broadcast television and computer-controlled visual display. Understanding the relationship between digital data and resulting radiant output is critical when these devices are used as stimulus generators for visual experiments, or to define a digital representation of an image in colour reproduction.

1.2 Purpose

The purpose of this technical report is to establish the relationship between digital data and measured spectral radiance and CIE tristimulus values for computer-controlled CRT displays. Although this report uses the 1931 2° CIE standard observer, it also applies to the 1964 10° standard observer. In addition, recommendations will be made for instrumentation specifications and measurement procedures that maximise colorimetric accuracy.

1.3 Scope

This technical report applies only to CRT technology. The effectiveness of the procedures contained herein depends on certain operating characteristics of the CRT such as channel and spatial independence, and on viewing distances and refresh rates in order for CIE colorimetry to apply to CRT stimuli. This report is intended to account for macroscopic properties of CRT displays on the order of hundreds of pixels; corrections for spatial inhomogeneities are considered only briefly.

2. METROLOGY

2.1 Overview

Measurements of the radiant output of colour CRT displays are performed in order to characterise their spectral, colorimetric, spatial and temporal properties. At the viewing distances, video rates and phosphor persistence typical of broadcast and computer graphics CRTs, it is assumed that the CRT is a steady-state emitter of optical radiation such that colorimetry applies.

CRT displays are optical radiation sources and as such, are treated as any extended diffuse radiator. Pertinent CIE publications include *Publications No. 18.2, The Basis of Physical Photometry, 2nd Ed.*,¹ *No. 38, Radiometric and Photometric Characteristics of Materials and Their Measurement*,² *No.41, Light as a True Visual Quantity: Principles of Measurement*,³ and *No. 63, The Spectroradiometric Measurement of Light Sources*.⁴ Since colorimetric properties are often computed from spectroradiometric data, *Publication No. 15.2 Colorimetry, 2nd Ed.*⁵ is also important. The International Organization for Standardization, ISO, has published colorimetric requirements for visual displays used in office settings, ISO 9241-8.⁶ The European Broadcasting Union, EBU, has published a technical report: *Methods of Measurement of the Colorimetric Performance of Studio Monitors*.⁷ Many journal articles and texts have been written on the subject of CRT metrology; some are referenced in CIE *Publication No. 87, Colorimetry of Self-Luminous Displays - A Bibliography*.⁸ Recent standards include the American Society for Testing and Materials (ASTM) *E1336, Obtaining Colorimetric Data From A Video Display Unit by Spectroradiometry*,⁹ *E1341, Obtaining Spectroradiometric Data from Radiant Sources for Colorimetry*,¹⁰ and *E1455, Practice for Obtaining Colorimetric Data From a Visual Display Unit Using Tristimulus Colorimeters*.¹¹ The ASTM standards are particularly useful because they give practical methods of calibration, the process of anchoring various radiometric scales in a manner traceable to national scales; verification, where the

calibration is verified using independent devices from those used during the calibration step; measurement; and tristimulus integration, where sampling interval and bandwidth is considered.

Given the wealth of pertinent literature, this chapter will be confined to brief descriptions, methodologies, and recommended precision and accuracy specifications where known.

2.2 Spectral instrumentation

2.2.1 Overview

A spectroradiometer is a device that measures a radiometric property of an optical radiation source as a function of wavelength and minimally contains a dispersing element and detector. It measures either spectral radiance if configured with a limiting aperture or spectral irradiance if configured without a limiting aperture. In general, irradiance measurements are used to characterise the average properties of a large portion of the CRT faceplate while radiance measurements characterise several pixels.

2.2.2 Design Criteria

Four critical spectroradiometer design issues are wavelength range, bandpass width, wavelength sampling increment, and dynamic range. The wavelength range should extend at least to 720 nm since the red phosphor has appreciable emission near 710 nm. Bandpass width depends on requirements for spectral resolution (small bandpass better resolves highly wavelength-selective spectra without additional signal processing) and signal to noise (large bandpass improves signal to noise). Bandpass width and sampling increment are interrelated. Ideally, the sampling interval should match the bandpass to avoid under or over sampling. Wavelength accuracy is critical when measuring the chromaticities of each channel. Errors in chromaticities cause errors in the colorimetric characterisation of the entire CRT colour gamut.

An analysis was performed¹² to determine wavelength accuracy requirements where the spectral irradiance of a broadcast monitor phosphor set was measured with a 2,5 nm bandpass every 1,2 nm between 240 nm and 870 nm. The data were interpolated to every 0,1 nm using Lagrangian interpolation. The CIE 1 nm colour matching function data for the 1931 standard observer were similarly interpolated. The 0,1 nm data from 360 nm to 830 nm were used to calculate CIE tristimulus values. The effect of linear wavelength error on colorimetric accuracy was simulated by shifting the measurements in 0,1 nm increments in either positive or negative directions and recalculating tristimulus values. CIELAB colour differences were calculated between the original measurements and the wavelength error measurements where the CRT peak white was used to define the white object colour stimulus (X_n , Y_n , and Z_n) in the CIELAB equations. The results are shown in Table 2.1. In general, colorimetric errors are largest towards the edge of the colour gamut. Thus, the errors reported for the primaries are typical of the largest errors that might occur if the entire colour gamut was evaluated. With a 0,1 nm shift, colorimetric error was as high as $0,36 \Delta E^*_{ab}$. A 0,5 nm shift produced a ΔE^*_{ab} of 1,78.

In CIE Publication 63,⁴ a wavelength accuracy of $\pm 0,1$ nm is recommended to insure the highest accuracy when determining the chromaticities of fluorescent sources ($\pm 0,0001$ in the calculation of xy chromaticities). This is equivalent to setting the colour balance of two monitors with different phosphor sets to the same correlated colour temperature (and luminance) or displaying uniform colour patches to simulate homogeneous surface colours and having the displays visually match. For pictorial stimuli, the accuracy tolerance can be relaxed to $\pm 0,5$ nm. A perceptibility experiment by Stokes, et al.¹³ using pictorial images as test stimuli displayed on a CRT resulted in average CIELAB colour differences between an original and perturbed image in the range of 2,0 to 2,5 before observers could perceive a just noticeable difference. This colorimetric difference corresponds to a wavelength accuracy in the range of $\pm 0,5$ nm based on Table 2.1.