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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO ~~documents~~document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 04, *Ergonomics of human-system interaction*.

A list of all parts in the ISO 9241 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides an overview of recent research on applying the optical reflection measurement methodology for flat direct view electronic displays to electrophoretic displays (EPDs). This document contributes background to ~~revisions of~~ ISO 9241-307~~;~~, ISO 9241-305 and ISO 9241-303~~ to accommodate~~, providing information regarding reflective displays in ambient indoor and outdoor illumination environments defined by CIE 015:2018 and CIE S017:2020.~~;~~

Reflective displays convey information by modulating the reflected light, using independently controlled segments or pixels. Any reflective display performs the following two basic optical functions~~:~~, either equally for all wavelengths achromatically or for selective wavelengths chromatically:

— reflecting ambient illumination towards the human observer~~, and~~ ;

—modulating the amount and spectral distribution of the reflected light~~, either equally for all wavelengths achromatically or for selective wavelengths chromatically.~~ .

For example, ~~EPD~~EPDs use electrically charged pigments to reflect and modulate light. Opaque white pigments with near-Lambertian reflection characteristics form the paper-like, diffuse reflecting background. Light-absorbing black pigments attenuate the reflected light as traditional ink does on paper. These properties differentiate EPDs from other display technologies by its paper-like appearance that offers a wide range of viewing directions and sunlight readability. Other properties are low power consumption and the absence of flicker. Other known reflective display technologies use reflectors with metallic, mirror or retroreflective characteristics, combined with diffusers, achromatic reflection modulators (for example liquid crystal shutters) and a colour filter array (CFA). EPDs are used in static and mobile applications including e-readers, wearables and signage for both indoor and outdoor applications.

A reflective display ~~needs~~must have ambient illumination for the displayed information to be visible. Ambient illumination has directional and diffuse components. In outdoor environments, direct sunlight is the directional component, and skylight the diffuse component. In indoor environments, the diffuse component is dominant, e.g. diffuse daylight through windows and light is scattered by walls and ceiling. In addition, specular reflection of light sources of various sizes (from small luminaires to large windows) has the potential to obliterate the information on display screens. This document ~~will explain~~explains how to separately measure the display's reflection characteristics under specific measurement illumination conditions, e.g. off-specular directional, hemispherical-diffuse, and specular variable aperture source (VAS) illumination. The three fundamental reflection components ~~—~~(specular, haze, and Lambertian~~—~~) are measured separately and as a function of illumination source size. Once the reflection coefficients for each illumination geometry are measured, the reflected luminance from each illumination component is determined, and the infinite variety of ambient multi-source illumination is expressed as a summation of reflected illumination components from these sources. The total spectral radiance entering the observer's eye when viewing a display is then predicted as a summation of all the ambient light components reflected into the direction of viewing. The contributions from each source are scaled according to their irradiance spectra for specific in- and outdoor illumination environments.

This document includes examples of standardized indoor and outdoor illumination conditions, and ~~use~~uses EPDs to illustrate the measurement methods.

~~Title (~~Ergonomics of human-system interaction~~—~~ —

Part 313: Optical measurement methods for reflective displays~~)~~

1 Scope

This document ~~gives~~provides background information and a validated methodology for optical reflection measurements for flat direct view electronic displays. This document includes calculation methods for using measured reflection coefficients to predict display performance in specific indoor and outdoor ambient illumination conditions.

This document demonstrates optical measurements of electrophoretic displays (EPDs), as a reflective electronic visual display technology; many methods ~~will be~~are also applicable to other appropriate reflective and emissive displays. This document does not include a methodology for ergonomics evaluation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9241-302, *Ergonomics of human-system interaction — Part 302: Terminology for electronic visual displays*

ISO 9241-303, *Ergonomics of human-system interaction — Part 303: Requirements for electronic visual displays*~~.~~

ISO 9241-305:2008, *Ergonomics of human-system interaction — Part 305: Optical laboratory test methods for electronic visual displays*~~.~~

~~ISO 9241-307, *Ergonomics of human-system interaction — Part 307: Analysis and compliance test methods for electronic visual displays.*~~

~~ISO/CIE 23539:2023(E) *Photometry — The CIE system of physical photometry.*~~

3 Terms, definitions and abbreviated terms

~~4.1~~3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9241-302, ISO 9241-303, ISO 9241-305 and the following apply.

ISO and IEC maintain ~~terminological~~terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

~~4.1.1~~3.1.1
reflective display
electronic display device that modulates light from an external source by reflection, using independently electronically controlled segments or pixels

Note 1 to entry: Any reflective display consists of at least two basic optical elements: reflector and reflection modulator. The reflector reflects ambient light back towards the human observer; the reflection modulator changes the reflectance either equally for all wavelengths for an achromatic display or in a spectrally selective manner for a colour one.

~~Note2~~ Note 2 to entry: Information on reflective displays is only visible in ambient illumination.

~~4.1.2~~3.1.2

electronic paper display

reflective display ~~(~~(3.1.1) having diffuse reflection characteristics with a wide range of viewing directions, holding static information with no or low power consumption and without flicker

Note 1 to entry: In literature, the acronym EPD often stands for "~~Electronic Paper Display~~electronic paper display" as well as for "~~ElectroPhoretic Display~~electrophoretic display." In this document, EPD stands for electrophoretic display, not electronic paper display.

Note 2 to entry: There are many short forms for electronic paper display, including e-paper, electrophoretic ink, electronic ink or e-ink. Any such short forms that are not clearly defined, refer to a specific technology or product, or are proprietary or trademark-protected, are not used in this document.

~~4.1.3~~3.1.3

electrophoretic display

EPD

electronic paper display ~~(~~(3.1.2) using electrically charged pigments to reflect and modulate light~~: opaque~~

Note 1 to entry: Opaque white pigments form the diffuse reflecting background for black or colour pigments that absorb or spectrally attenuate reflected light in the same way as traditional ink on paper.

Note ~~1~~ 2 to entry: ~~In this document, EPD stands for electrophoretic display.~~

~~Note 2 to entry:~~ This document reports measurement examples on ~~EPD.~~electrophoretic display (EPD).

~~4.1.4~~3.1.4

electronic reader

e-reader

handheld electronic device that uses an *electronic paper display* ~~(~~(3.1.2) in general, and an ~~*EPD* (~~*electrophoretic display* (3.1.3) in particular, to present visual information

~~4.1.5~~3.1.5

emissive display

electronic display that ~~contains its own~~modulates light by emission from an internal source~~(s) of light~~, using independently electronically controlled segments or pixels

Note 1 to entry: This light is either produced by the transducer itself or provided by one or more internal light source(s) modulated by the transducer.

Note 2 to entry: Information on emissive displays is visible without ambient illumination, and reflected ambient illumination is possibly disturbing to the viewing of emissive displays, see IEC 62977-2-2 ~~Ed1.0: 2020~~.

~~4.1.6~~3.1.6

information-dependent reflection

reflection off a *reflective display* ~~(~~(3.1.1) that is modulated according to the visual information to be displayed

Note 1 to entry: This is also referred to as information-dependent reflection or visual information.

~~4.1.7~~3.1.7

unwanted reflection

reflection off a *reflective display* ~~(~~(3.1.1) that is not modulated according to the visual information to be displayed~~.~~

Note 1 to entry: This is also referred to as information-independent reflection.

Note 2 to entry: Examples are reflections from the first surface of the display device.

Note 3 to entry: Specular reflections of ambient light sources (luminaires, lamps, windows, etc.) on a display screen are unwanted reflections. They reduce the contrast and thus the legibility of displayed information. Often, they are the cause of glare, leading to discomfort or inability to recognize the information for the user, see ISO 9241-305: 2008, 5.4.11, and CIE S017:2020.

~~4.1.8~~3.1.8

contrast under ambient illumination

contrast of a *reflective display* ~~(~~(3.1.1) where both hemispherical-diffuse and directional illumination are incident to its surface at defined geometry, illumination spectra, and illumination levels that simulate a realistic lighting environment

3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

1-D	one-dimensional
2-D	two-dimensional
AG	anti-glare
B&W	black-and-white
BRDF	bi-directional reflection distribution function
BSDF	bi-directional scattering distribution function
CCD	charge-coupled device
CFA	colour filter array
CR	contrast ratio
DUT	display under test
EPD	electrophoretic display
IR	illuminance ratio
LCD	liquid crystal display
LED	light-emitting diode
LMD	light measuring device
OFT	optical Fourier transform
PSF	point spread function
VAS	variable aperture source

~~5~~4 Reflective display technology

Reflective displays convey information by modulating the amount and spectral distribution of reflected light. For displaying information, the display area is divided into independent electronically-controlled segments (for text) or pixels (for graphics and images). Any reflective display performs two basic optical functions: reflecting ambient illumination, and modulating the amount and spectral distribution of the reflected light.

The optical characteristics of ambient light reflections determine the appearance of the reflective display. In order to mimic paper, the display background is white. For this, its reflection is as high as possible, spectrally uniform, and diffuse with a near-Lambertian scatter characteristic (independent of viewing direction).

The optical characteristics of the reflected light modulation determine whether the viewer sees achromatic or colour information. Modulators attenuate (subtract from) the reflected light within the visible part of the spectrum (~~ca. 380nm~~approximately 380 nm to ~~730nm~~730 nm). In an achromatic display, the modulator subtracts light about equally for all wavelengths; in a colour display, the subtraction is wavelength-selective.

The various reflective display technologies use different means to reflect and modulate ambient light as much and as effectively as possible.[7]~~.~~

~~Electrophoretic reflective displays (~~EPDs~~)~~ use electrically charged pigments to reflect and modulate light~~: opaque~~. Opaque white pigments with paper-like (Lambertian) reflection characteristics form the white background in which contrasting black or colour pigments are used that absorb or spectrally attenuate reflected light in the same way as traditional ink on paper.[8]~~.~~ Diffuse white reflection ensures paper-like appearance over a wide range of viewing directions. EPDs are preferred in electronic paper due to their paper-like optical characteristics, combined with low power consumption and the absence of flicker. They are suited to a wide range of stationary and mobile applications including e-readers, wearables, signage, and are used in indoor and outdoor environments where readability in ambient lighting is critical. The measurement examples in this document are confined to EPD for their widespread use as electronic reading devices.

Other reflective display and electronic paper technologies include gain reflectors, such as mirrors or retroreflectors, combined with diffusers to improve viewing direction range. Some technologies switch reflection by using liquid crystal shutters or electrophoretic nanoparticles that disrupt retroreflection, and use ~~colour filter arrays (CFA)~~CFAs to colour the reflected light. Electrowetting colour displays have three layers of light switching cells (cyan, magenta, and yellow) in front of a reflector. Others combine the functions of reflector and spectral modulators into "colour-changing mirrors" i.e. mirror-like reflectors that colour the reflected light (phase-changing, electrochromic, or interferometric devices).

Both reflector and modulator of the display are responsible for the information-dependent reflection. For the background to have the maximum possible luminance, the display is expected to reflect as much incident light as possible. An ideal white diffuse reflector has a diffuse reflectance of close to 100 %. Mirror reflectors and retroreflectors have a higher reflectance compared to a diffuse reflector but only within a narrow range of viewing directions. Even if an efficient reflector is achieved, unwanted reflections (perceived as glare) will change the display white, and reduce contrast and colour modulation. A variety of sources potentially degrade these visual attributes. Surface reflection is specular or diffuse (haze), depending on whether the display has a glossy or a matte anti-glare (AG) surface. Optical losses come from reflection and scatter at internal optical interfaces. Transparency and aperture ratio of optical layers above the reflector (for example liquid crystal shutters and CFA) reduce the incident light on the inbound pass then, after reflection, again on the outbound path. The aperture ratio or effective pixel area is defined as the ratio of the optically active area to that of the total pixel area. The optical properties of the reflective display's layer structure and its surface differentiate electronic paper from printed paper~~[1]~~.

NOTE Not even printed paper is free of disturbing reflection when it has a glossy surface called "coated paper" that is otherwise preferred for its better colour reproduction.

~~[1] Not even printed paper is free of disturbing reflection when it has a glossy surface called "coated paper" that is otherwise preferred for its better colour reproduction.~~

~~6~~5 General optical measurement methodology

~~6.1~~5.1 ~~General concept of spectral~~Spectral radiance of display in ambient illumination

Although reflective displays have become widely used in e-readers, the development of appropriate optical measurement methods has not kept pace. Users of e-readers compare them to not only emissive tablet displays, but also to printed materials. Optical measurement standards exist for emissive electronic displays and conventional printing on paper~~. Neither are entirely~~, for example the measurement standards issued by IEC on liquid crystal displays (LCD), and specifications for conventional printing on paper, for example the Specifications for Newsprint Advertising Production (SNAP) and the Specifications for Web Offset Printing (SWOP). Standards covering these topics are not suitable for reflective displays because of the fundamentally different ways that ambient illumination affects the information displayed on emissive displays, reflective displays, and printed paper~~:~~.

— Emissive displays show information by modulating the emitted light. Reflected ambient light is always disturbing as it adds background noise to the desired emissive signal. Therefore, the optical characteristics of emissive displays are measured in a darkroom. Ambient light is only of interest when determining the effect of unwanted reflections~~2~~.1). The measurement of emissive display characteristics under ambient light is addressed in IEC 62977-2-2 ~~Ed1.0: 2020.~~.

— Reflective displays modulate ambient light to show information. Information on reflective displays is only visible in ambient illumination, but direct reflection of the illumination source is perceived as glare. Whether the reflection is information-dependent or unwanted will depend on the illumination~~/~~ and viewing geometry. Therefore, reflection measurements differentiate between information-dependent and unwanted reflection in order to separate one from the other. Information-dependent reflection is measured with the exclusion of unwanted reflection.[9] In practice, handheld mobile display users automatically do this by tilting their displays to avoid unwanted reflection. In some cases, unwanted reflection is measured for applications such as signage where it is unavoidable. Therefore, measurement illumination for reflective displays has specific spectral distribution and geometry.[10]

— Print paper with a matte surface (office print paper, newsprint) exhibits efficient Lambertian scatter of incident light. If the surface is matte, contrast is maintained over a wide range of viewing angles, and there is no glare from specular reflection. Glossy surfaces of coated paper (magazine print) are not free of glare.

The recognition of these differences between emissive displays, reflective displays and printed paper resulted in the development of measurement standards for electronic paper displays, IEC 62679-1-1 ~~Ed1.0: 2014,~~ and IEC 62679-3-1 ~~Ed1.0: 2014 with their optical characterisation requiring~~. Optical characterization, as specified in these documents, requires the following steps:

a) ~~Identifying~~identifying the fundamental components of ambient illumination, then ~~for each illumination component~~ specifying the geometry, illumination levels and spectra~~,~~ for each illumination component;

b) ~~Identifying~~identifying the fundamental components of information-dependent and unwanted reflection, then ~~for each reflection component~~ specifying the measurement methods~~,~~ for each reflection component;

~~2 For example, ISO 9241-305: 2008 specifies viewing requirements for emissive desktop displays in an office environment where glare, caused by unwanted reflections of windows, light sources, or brightly illuminated objects, is present. ISO 9241-307: 2008 states that display and lighting design can minimize disturbing reflection to satisfy minimum contrast requirements.~~

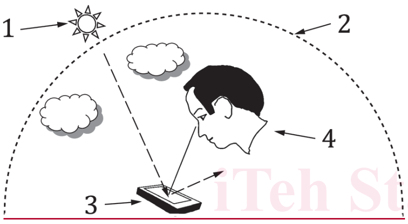
1) For example, ISO 9241-305 specifies viewing requirements for emissive desktop displays in an office environment where glare, caused by unwanted reflections of windows, light sources, or brightly illuminated objects, is present. ISO 9241-307 explains that display and lighting design can minimize disturbing reflection to satisfy minimum contrast requirements.

c) Estimatingestimating the total spectral radiance of the display in ambient illumination conditions as the sum of its reflective components.

From the total spectral display radiance, the complete photometric and colorimetric properties of the display under multi-source illumination are determined.

6.25.2 General concept of ambient illumination

Ambient illumination comes from many sources, each with its own spectral distribution, angular distribution, and direction of incidence to a display. Users in general view reflective displays in both indoor and outdoor lighting environments as shown in Figure 1. Viewers of handheld screens tend to avoid unwanted reflections. Reflection measurement specifications made in IEC 62679-3-1 Ed1.0: 2014 specify measurements that exclude unwanted reflections as well as measurements that include reflected components that are not modulated (e.g. front surface reflections).



Key

sun

1

Inserted Cells

1

2 sky

3 display

Key

1 sun

2 sky

3 display

4 display viewer

Figure 1 — Outdoor ambient illumination environment for display viewing.

The ISO 9241-300 series in general specifies the viewing requirements for emissive displays in an indoor work environment. Ambient indoor illumination is potentially "disturbing,", i.e. liable to cause glare to be controlled and its effect minimized. ISO 9241-307 distinguishes between a diffuse background illuminance ("design screen illuminance", specified in lxlux), and those light sources with specified source aperture angles, luminance and CIE Illuminantilluminant spectra that potentially cause unwanted reflections (see ISO 9241-305:2008, 5.2.4 and 5.4.11, ISO 9241-307: 2008, CIE 015:2018, and CIE S017:2020). For reflective displays,