Requirements for new technologies becoming part of on-screen work as well as directions for their implementation, especially in standardization activities

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Research
Project F 1846

Bundesanstalt für Arbeitsschutz
und Arbeitsmedizin

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CR	(luminance) contrast ratio (CIE 17.4/IEC 50, 845-02-47)
E	illuminance [lx] (CIE 17.4/IEC 50, 845-01-38)
ΔE^*_{uv}	CIELUV colour difference (CIE 17.4/IEC 50, 845-03-55)
g	uniformity ratio of illuminance (CIE 17.4/IEC 50, 845-09-58)

L	luminance [cd/m²] (CIE 17.4/IEC 50, 845-01-35)
q	luminance coefficient [1/sr] (CIE 17.4/IEC 50, 845-04-71)
R_a	colour rendering index (CIE 17.4/IEC 50, 845-02-61)
R', $R'(\lambda)$	Reflectometer value (CIE 17.4/IEC 50, 845-04-72)
s	visual acuity (CIE 17.4/IEC 50, 845-02-43)
$S(\lambda)$	relative spectral distribution (CIE 17.4/IEC 50, 845-01-18)
T	correlated colour temperature [K] (CIE 17.4/IEC 50, 845-03-50)
u',v'	CIE 1976 chromaticity coordinates (CIE 17.4/IEC 50, 845-03-53)
$V(\lambda)$	spectral luminous efficiency, photopic vision (CIE 17.4/IEC 50, 845-01-22)
$V'(\lambda)$	spectral luminous efficiency, scotopic vision (CIE 17.4/IEC 50, 845-01-22)
x,y	CIE 1931 chromaticity coordinates (CIE 17.4/IEC 50, 845-03-33)
$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$	CIE 1931 colour matching functions (CIE 17.4/IEC 50, 845-03-30)
X, Y, Z	tristimulus values (CIE 17.4/IEC 50, 845-03-22)
α	viewing angle [']
γ	display gamma (EBU Tech. 3273-E, VESA FPDM)
$\varphi(\lambda)$	colour stimulus function (CIE 17.4/IEC 50, 845-03-03)
λ	wavelength [m, nm] (CIE 17.4/IEC 50, 845-01-14)
ρ, $\rho(\lambda)$	reflectance (CIE 17.4/IEC 50, 845-04-58)
Φ	luminous flux [lumen] (CIE 17.4/IEC 50, 845-01-25)
Ψ	character height ['] (ISO 9241-3, ISO 13406-2)
ϑ	temperature [°C]

Indices:

A	Area	D	diffuse
H, L	higher, lower value	S	specular
r	reflected value	i	i = 1, 2, 3, ... n
min	minimum value	max	maximum value
panel	Place of origin of the image	screen	Screen as used in front projection
obs	observed	EXT	extended

Anforderungen an neue Technologien bei Bildschirmarbeit und Erarbeitung einer Handlungshilfe zur Umsetzung, insbesondere im Bereich der Normung

Kurzreferat

Mit diesem Forschungsbericht soll ein konstruktiver Beitrag zur Restrukturierung derjenigen Teile der Normenreihe ISO 9241 gegeben werden, die sich auf die visuellen Anforderungen an die Anzeige beziehen. Dies erfolgt vor dem Hintergrund, dass heutige Anzeigen-Technologien nicht mehr nur in dem als klassisch zu bezeichnenden Büro- und Verwaltungsbereich eingesetzt werden, sondern auch in anderen Einsatzfeldern der Bildschirmarbeit (mobile Arbeit, Krankenhaus, Produktion usw.).

Die verschiedenen neuen Technologien mit ihren visuellen Eigenschaften als auch die mit der visuellen Anzeige durchgeführten Aufgaben und die Eigenschaften der Umgebungen, in denen die neuen Technologien eingesetzt werden, werden untersucht und beschrieben.

Basierend auf dem Zusammenspiel zwischen Benutzer, Aufgabe, Umgebung und Technologie erfolgt eine Ableitung von visuellen Anforderungen an neue Technologien.

Weiterhin werden Vorschläge zur Struktur des gerade neu entstehenden Standards ISO CD 18789 (ISO 9241-xx) gegeben.

Schlagwörter:

Bildschirmarbeit, neue Technologien, Hardware-Ergonomie, visuelle Anzeige, Restrukturierung ISO 9241.

Requirements for new technologies becoming part of on-screen work as well as directions for their implementation, especially in standardization activities

Abstract

This research report aims at constructive support for restructuring those parts of the ISO 9241 series, which deal with requirements for visual displays. Among other aspects, the restructuring of ISO 9241 becomes necessary since the scope of application of current visual display technologies expands from the traditional office environment to other work environments (e.g. mobile work environments, hospital work places, production work places, etc.).

The various new technologies with their new visual properties as well as the supported tasks and environmental conditions are analysed and described.

Based on the inter-relationship between user, task, environment and technology, general recommendations for new technologies are being derived.

Furthermore, proposals are made for structuring the emerging Standard ISO CD 18789 (ISO 9241-xx) „Ergonomics of human system interaction – Ergonomic requirements and measurement techniques for electronic visual displays“.

Key words:

work with visual displays, new technologies, hardware ergonomics, visual displays, restructuring of ISO 9241.

Exigences imposées aux nouvelles technologies pour le travail sur écran et élaboration d'une aide pour la mise en application, en particulier dans le domaine de la normalisation

Bref exposé

Ce rapport de recherche a pour but d'aider à restructurer de manière constructive les parties de la série de normes ISO 9241 se rapportant aux exigences visuelles de l'affichage. Ceci est fondé sur le fait que les technologies d'affichage actuelles ne sont plus uniquement utilisées dans le domaine des bureaux et de l'administration classiques mais aussi dans d'autres domaines d'application du travail sur écran (travail mobile, hôpital, production, etc...).
Les diverses nouvelles technologies avec leurs caractéristiques visuelles, les travaux réalisés avec l'affichage visuel ainsi que les caractéristiques de l'environnement dans lequel les nouvelles technologies sont utilisées, sont analysés et décrits dans ce rapport.
Les exigences visuelles imposées aux nouvelles technologies découlent de l'interaction entre l'utilisateur, la tâche à effectuer, l'environnement et la technologie. En outre, des propositions sont émises concernant la structure de la nouvelle norme ISO CD 18789 (ISO 9241-xx) actuellement en cours d'élaboration.

Mots clés:
Travail sur écran, nouvelles technologies, ergonomie du matériel, affichage visuel, restructuration ISO 9241.

1. Introduction

Due to the significance of visual display units (VDU) as a central tool across work environments as well as the rapid technological development, the safe and ergonomic construction of products for work with visual displays is of great importance.
As a basis for ergonomic evaluation of relevant products, the standard ISO 9241 is available, which was developed in the past 15 years. ISO 9241-3/-7/-8 mainly cover the ergonomic requirements and test procedures for the Cathode Ray Tube (CRT) technology. Concerning flat panel displays the standard ISO 13406 is now available.

The following weakness is visible in ISO 9241 as well as ISO 13406:

a) Mixing of requirements related to the product and the working environment as well as regulatory use

Research report No. 16 from the German Commission for Occupational Health, Safety and Standardization (KAN) dated December 1997 also refers to this issue. This leads to less transparency for the intended target groups such as manufacturers, product users, system developers as well as supervisors for health and safety. In addition compliance tests for the target groups become complicated.

b) Related to a fixed technology, tasks and environment

ISO 9241 was written with Cathode Ray Tubes (CRT) in mind and ISO 13406 with focus on flat panel displays. Both of the standards were restricted to office tasks and office-like environments. This restriction makes the integration of new technologies, tasks and environments difficult. Requirements are the same for different technologies, but the test procedures for showing compliance will change. In addition, work with visual displays has changed. This work is no longer stationary, indoor; it changed to mobile work with both indoor and/or outdoor conditions. Therefore, standardization has to take this shift into account.

c) Mixing of requirements related to the hardware and the software

A few requirements are purely controlled by software others purely by hardware. There are also requirements, which are controlled by both, hardware and software. For differentiation and explanation there is no guideline available. Compliance tests often become complicated and are suitable for experts only. An insight into these problems is beyond this report.

d) „old“ and missing requirements, mistakes

Some requirements were based on technology capability at the time of development of the standards. These requirements should be revised. An analysis of missing/additional requirements should be made. Mistakes should be corrected.

e) Alternative evaluation/test methods

Today‘s compliance tests of VDUs are mainly based on measurements in optical labs. Alternative evaluation/test methods should be developed to keep the standard usable and attractive for the different user groups.

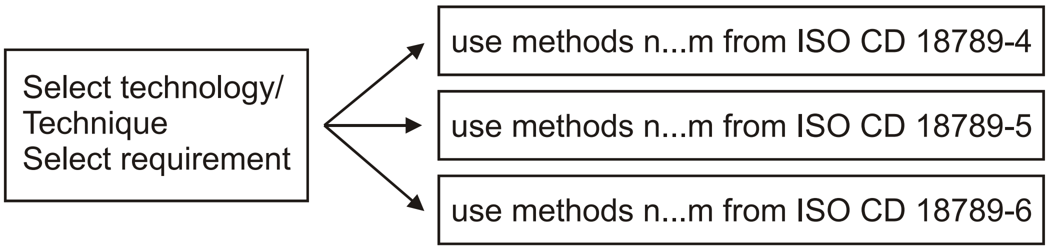
A possible solution can be achieved by reconstruction of standards ISO 9241 und ISO 13406. This reconstruction has already been decided on by ISO TC159/SC4. Concerning the reconstruction of ISO 9241-3/-7/-8 and ISO 13406 working group 2 of ISO/TC159/SC4 prepared a new work item ISO CD 18789 (ISO 9241-xx) „Ergonomics of human system interaction – Ergonomic requirements and measurement techniques for electronic visual displays“. This standard should contain seven parts with the following proposed structure:

Part	Title and Contents
1	**Introduction and overview** - Orientation to the user - Integrated versus modular products - Work environments
2	**Terms and definition** Definition of recurrent terms from photometry, colorimetry, geometry, display technology and fonts

3	**Ergonomic requirements** General requirements for all displays: Interaction, Unwanted artefacts, Attractiveness, Usability and controllability Special requirements for displays: Recognition of information, Fidelity
4	**Usability laboratory test methods** List of usability tests
5	**Optical laboratory test methods** Definition and description of photometric and colorimetric measurements
6	**Workplace test methods** List of useful and valid workplace test methods with respect to e.g. the EU directive 90/270/EEC
7	**Analysis and compliance methods** Definition of conformance routes as needed by technology

Tab. 1-1 Proposals within ISO CD 18789 (ISO 9241-xx)

Part 7 of ISO CD 18789 (ISO 9241-xx) contains the different analysis methods and compliance methods for different technologies. The proposed procedure is as follows:



The new draft will have the following advantages:

- New technology as well as new test methods may be added easily due to the modular structure.
- The scope should cover new tasks and working environments.

Up to now the main work of WG2 was the development of the structure of the new standard. Detailed work was been partly completed. High expenditure and resources are needed for integration and completion of analysis and compliance methods.

The new standard refers mainly to the visual perception approach. Some questions and disadvantages arise:

- What about recording, generation and transmission of images?
- What about acoustic perception?
- What about anthropometric aspects such as weight and measures specific to mobile use of equipment?
- What about energy consumption as well as the environmental compatibility in relation to ergonomics issues?

This research report was prepared as part of a set of three research projects. The aim of this project is the construction and description of ergonomic recommendations regarding visual quality of new technologies as well as the preparation of constructive proposals for the new structure of ISO CD 18789 (ISO 9241-xx).

The two other projects F1798 and F1883 within the set of projects are also related to the content of ISO CD 18789 (ISO 9241-xx). Ergonomic recommendations for input devices and software are addressed there.

As part of the process of the coordination and treatment of the three projects it became clear that a substantial challenge exists in the solution of the following problems:

- Insufficient/indistinct definition of the wording used.
- Insufficient tuning of the standard parts to the needs of the target group (manufacturer/system developers respectively supervisors/users).
- Lack of framework for targeted application of the recommendations given in the standard.
- Consideration of interests according to article 95 respectively article 137/138 of the European Union treaty. Requirements for design of products are addressed primarily within the range of article 95 whereas requirements regarding selection and combination are primarily addressed in article 137/138.

To solve conceptual problems with the practical application of the standard the following framework with definitions is suggested by all research teams (see figure 1–1):

Ergonomic design principles describe standardized goals and represent state-of-the-art consensus across experts of the field. They represent fundamental rules to be further operationalized.

On the basis of ergonomic design principles recommendations must be derived, which can be product specific (range of article 95) or related to the selection and combination of products (range of article 137/138). These recommendations may be called „common“, „general“ or „generic“ and form part of the standard. Such recommendations are valid in general however they are need to be specified in the context of use in order to obtain measurable requirements.

Recommendations must therefore be translated into precise requirements. It is necessary to identify the context of use, in which a product is used. Concerning the product consistency (within the range of article 95) the **intended** context of use must be specified whereas the **actual** context of use has to be considered in the range of article 137/138. Development processes at the manufacturers side must deduce the intended context of use by realistic analysis of the actual context of use at user organizations, thus preparing usable new products.

Not all user requirements are context dependent. Such context independent requirements may be introduced as part of the standards.

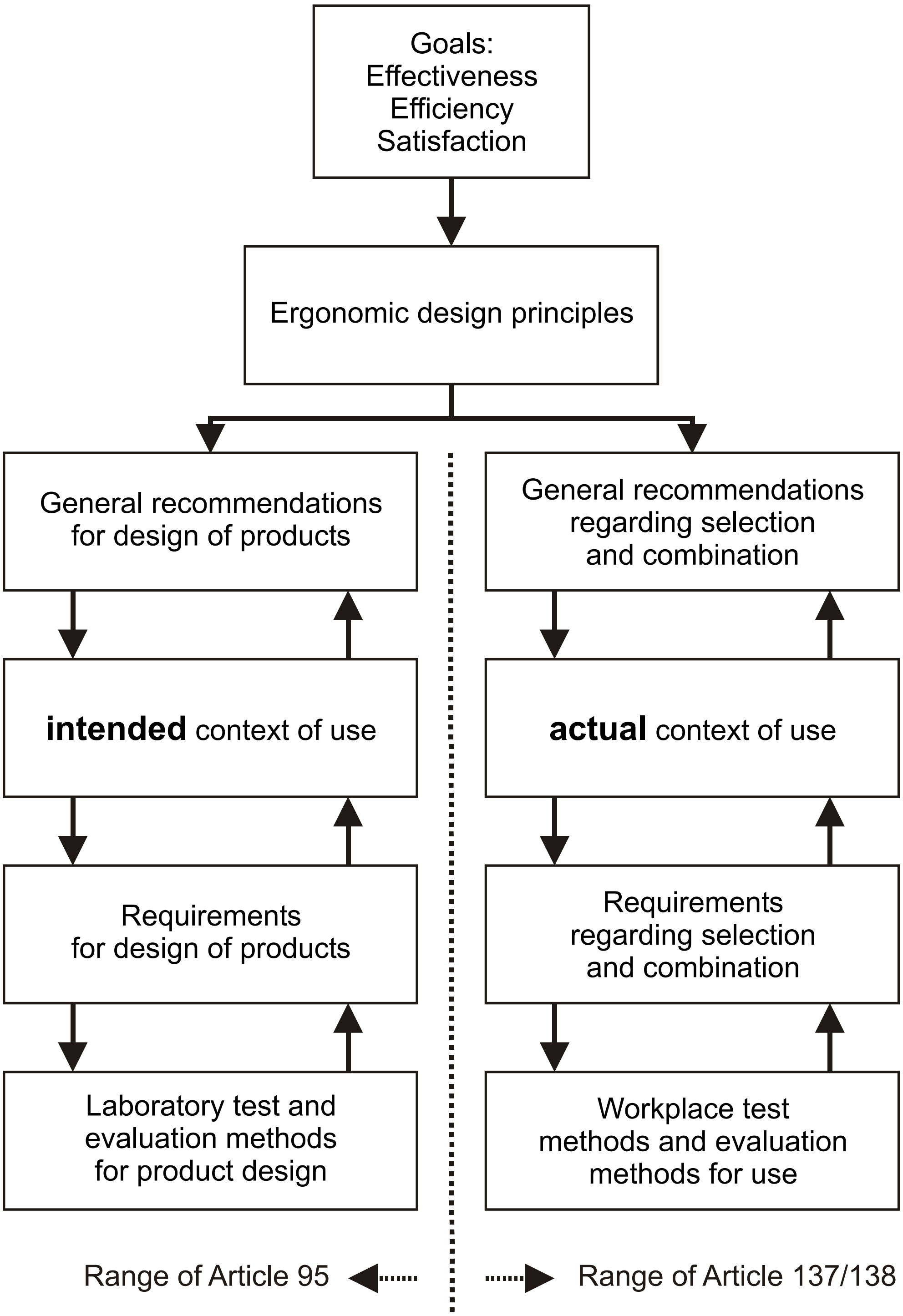


Fig. 1-1 Framework for ergonomic design, selection and combination of products

The given terms are organized from the general one to the specific one (top down). Based on ergonomic design principles, usually recommendations are derived. Followed by a specification of the intended context of use, measurable user requirements are being derived. These requirements may be checked using laboratory tests and evaluation test methods or also in the actual context of use of the user organization.

However also the reverse process (bottom up) is possible as shown in figure 1–1. In this case requirements are deduced from the existing specification of the context of use. Further, context-specific requirements are validated to be standard-compliant by the mapping them to the corresponding recommendations in the standard or mapping them to the principles themselves. Such a proceeding is suitable particularly for developers of standards themselves in order to ensure that the compiled standard corresponds to the logical framework represented in figure 1–1.

This report is structured as follows:

a) Identification of the actual context of use for work with visual displays

Due to the technological progress, the context of use must be revised by identification of the currently available relevant elements of the context of use.

b) Analysis of attributes of the actual context of use

The actual context of use covers a wider range of different technologies, tasks and environments. Their attributes are analysed, since they will influence visual perceived quality.

c) Analysis of interdependencies

Comments upon interdependencies between the elements of the context of use are given.

d) Structure of ISO CD 18789 (ISO 9241-xx)

Proposals for general recommendations are given as well as an outlook for the structure of ISO CD 18789-7.

e) Basic concepts for insuring visual perception

Some comments on basic concepts concerning contrast, luminance and relationship between geometric proportions of the visual display, displayed information and viewing conditions are given.

Note:

The final number of ISO CD 18789 has not yet been decided. In this light the number ISO 9241-xx is discussed. For the purpose of this research report the number ISO CD 18789 is used.

2. The actual context of use

Nowadays the terms „information society", "service society" or "communication society" are often used. The basis is the technological progress, which offers e.g. direct (mobile) availability of information, independent from the location of work. Information and knowledge can be exchanged faster than before. Knowledge can be replaced fast. On the other hand the technological progress combined with economical and political aims will lead to a change of working tasks and working processes.

So far this is an ongoing process with complex relationships and interdependencies. The speed of this process is increasing. In addition, people of each age are addressed, varying from education until retirement.

ISO 9241 is related to typical office environments. Due to the above-mentioned changes, the context of use of equipment as a basis for the scope of the standard must be reworked within the reconstruction of the standard. The work with visual displays must be viewed in total and is characterized by the following elements:

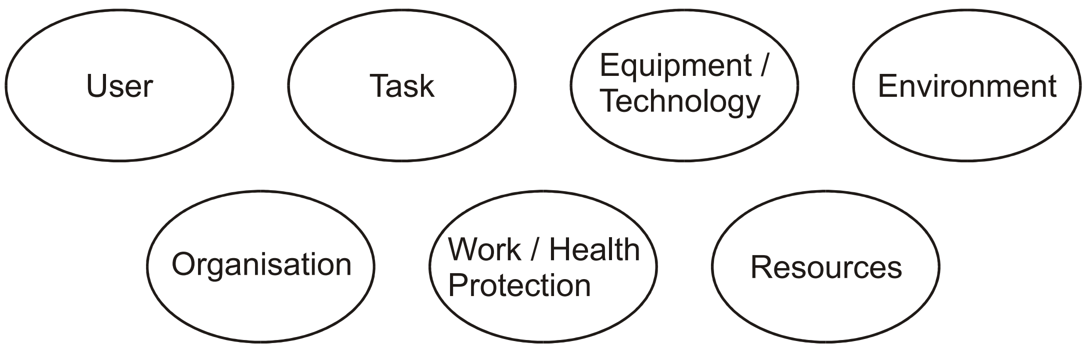


Fig. 2-1 Elements of the context of use „work with visual displays"

2.1. Identification

2.1.1. Identification of users

The existing standard ISO 9241 is related to a „general“ user who is „doing office work“. No information about the age is given. Therefore the natural degenerations of the physical and psychological efficiency, given by the age of the user, are not covered. This is especially relevant for the viewing conditions in conjunction with visual display terminals. Due to advanced work support with new technologies, these shall include changed requirements and needs of elderly people.

2.1.2. Identification of tasks

ISO 9141-11 defines tasks as required activities to achieve a goal. These activities are physical or cognitive. Our elementary senses are used for carrying out of these activities:

- Admission of information with the senses “seeing“, “hearing”, “smelling”, “tasting” “balance”, “touch” and “ kinaesthetic”
- Thinking (human information processing)
- Execution of physical actions

For mastering a task the elementary senses are put together as required. The complexity of this combination depends on the task as well as the technology used. An entire statement of all tasks is not possible. With advanced development of new (visual display) technologies there is an ongoing development of visual display tasks.

Within the work with new (visual display) technologies we detect the following activities:

Visual tasks

Definition according to ISO/FDIS 8995:

visual task: the visual elements of the task to be carried out.

Definition according to DIN 5035 Part 7:

a) taking in information displayed on the screen e.g.

- Reading
- Monitoring, controlling, observing

b) taking in information not displayed on the screen e.g.

- Reading

Hearing tasks

In an similar way:

The acoustic elements of the task to be carried out.

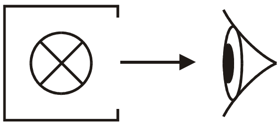
a) taking in information from the intended acoustic source
b) taking in information from other acoustic sources

Physical tasks

- Speaking
- Operation of input devices (controls and keys: e.g. writing; pen: e.g. writing, drawing, painting; mouse)

2.1.3. Identification of new visual display technologies and equipment

Technology describes the technically available principle of the displayed image. Equipment in turn describes the used display technology in a specific product configuration with peripheral to make a technology usable for a task. A figure shows the simplified principle of operation of the technology. Hereafter a short description of different equipment is given.



2.1.3.1. Cathode Ray Tube Monitor

The heart of a Cathode Ray Tube (CRT) visual display is the CRT itself. A CRT consists of a tube made of glass. Phosphor is located on the inner side of the front glass. The phosphor is stimulated by an electron beam and will then radiate visible light. The intensity of light is modulated by the beam current.

Typical applications are:
Television since the mid 50s and computer monitors, first monochrome and later colour; gaming machines

Fig. 2-2 CRT Monitor
(Source: Avnet Applied Computing)

2.1.3.2. Plasma Display Panel

A Plasma Display Panel (PDP) works similar to familiar fluorescence lamps. Pixels are between two sheets of glass. The pixels are formed of tiny cells holding phosphors, gas and electrodes on the top and bottom. Electrical discharges cause the gas to emit ultraviolet light that excites the phosphor. The red, green and blue phosphor will then radiate visible light. The intensity of light is modulated by the number of ignitions per time in a complicated process.

Typical applications are: advertising, conference, education, training and television

Fig. 2-3 Plasma Display Panel
(Source: NEC)

2.1.3.3. Visual displays with Light-Emitting Diodes

Here light-emitting diodes (LEDs) are inorganic semiconductor diodes. Special semi-conductors are used to emit visible light for different colours. The light is emitted when excited by an electric current. LEDs produce narrow-band spectral distributions.

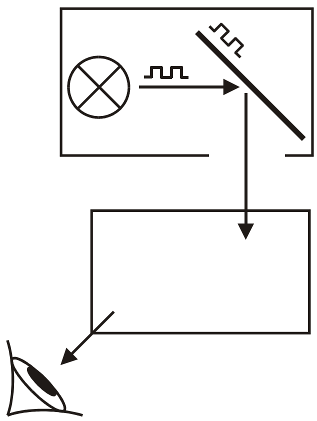
Typical applications are: Status indicator, seven-segment numeric display, matrix display, video screens, public advertising boards, traffic lights

Fig. 2-4 LED’s
(Source: OSRAM Opto Semiconductors)

2.1.3.4. Visual displays with Organic Light-Emitting Diodes

Within a visual display with Organic Light-Emitting Diodes (OLED) the pixels consist of cells with organic thin films placed between two conductors. When a voltage is applied, light is emitted by the organic films. The intensity of light is modulated by the applied current. OLED displays can be addressed via passive or active matrices. A first application is an OLED display in a car radio. Other applications and further substrate materials like flexible structures are under development.

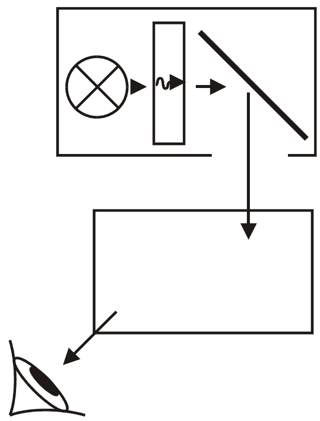
Fig. 2-5 OLED display in car radio
(Source: Pioneer)



2.1.3.5. Front projection with a digital micro mirror device

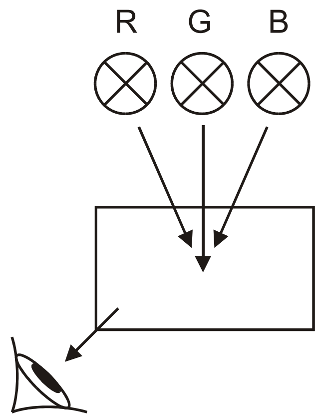
Light from an integrated light source is reflected on a digital micro mirror device (DMD). The light as well as the micro mirrors are modulated to produce images on a screen. Binary pulse width modulation is used to produce greyscale and colour filters to achieve colours. The screen is not integral part of the equipment, but integral part of the visual display.

Fig. 2-6 DLP™ (**D**igital **L**ight **P**rocessing) Projector
(Source: Benq)



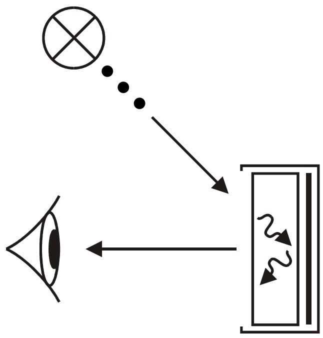
2.1.3.6. <u>Front projection with a Liquid Crystal device</u>

The light from an integrated light source is modulated by a transmissive Liquid Crystal (LC) device and projected onto a screen. The screen is not integral part of the equipment, but integral part of the visual display.



2.1.3.7. Front projection with CRTs

The light from three Cathode Ray Tubes is projected onto a screen. The screen is not integral part of the equipment, but integral part of the visual display.



2.1.3.8. Reflective Liquid Crystal Displays

The light from an external light source (ambient light) is modulated by a reflective Liquid Crystal Display (LCD). The intensity of light is modulated by an electric field via the LC layer.

This visual display type is widely used. Typical applications are:
displays in watches, printers, fax, scanner, calculators, household and medical appliances

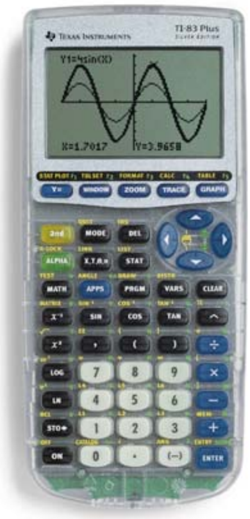
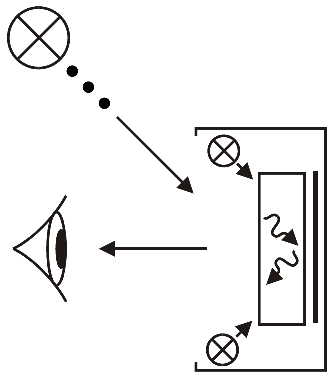


Fig. 2-7 Calculator
(Source: Texas Instruments)

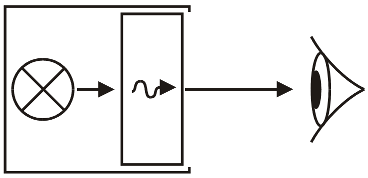


2.1.3.9. Reflective Liquid Crystal Displays with integrated front/side light

The light from an integrated front/side light unit or from an external light source (ambient light) is modulated by the reflective LCD. The intensity of light is modulated by an electric field via the LC layer.

Typical applications are:
PDA (Personal Digital Assistance), mobile phones

Fig. 2-8 Mobile phone
(Source: Nokia)

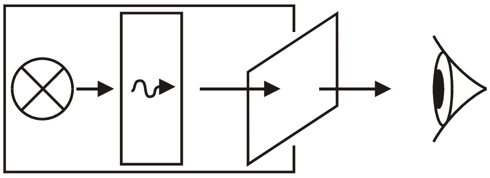


2.1.3.10. Transmissive Liquid Crystal Displays with integrated back light unit

The light from an integrated light source (back light unit) is modulated by an LCD. The back light unit and LCD are put together. Viewed from outside this visual display looks like an emissive visual display. The intensity of light is modulated by an electric field via the LC layer.

Typical applications are:
TFT-LCD computer monitors, Notebook/Laptop, Television (just emerging), Videophone, PDA

Fig. 2-9 LC Monitor
(Source: Avnet Applied Computing)

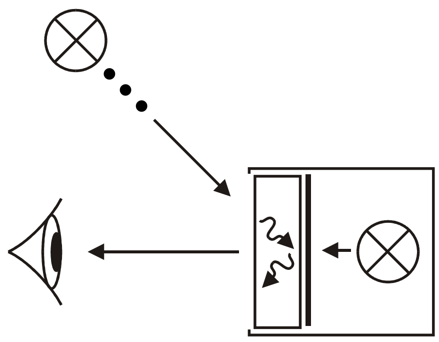


2.1.3.11. Rear Projection Monitor

The light from an integrated light source is modulated by a reflective or transmissive LC cell and projected on a screen. The screen is integral part of the equipment. The intensity of light is modulated by an electric field via the LC layer.

A typical application is:
rear projection on large TV screens

Fig. 2-10 Rear Projection Monitor
(Source: Samsung)



2.1.3.12. Transflective Liquid Crystal Displays with integrated back light unit

This is a combination of transmissive and reflective visual display. The light from an external light source (ambient light) is modulated by an LCD and reflected on semitransmissive reflectors. During self-luminous mode the light from an integrated back light unit is modulated by the LCD. The intensity of light is modulated by an electric field via the LC layer.

Typical applications are:
PDA (Personal Digital Assistance), mobile phones

Fig. 2-11 PDA with a pen
(Source: Handspring)

2.1.3.13. Further technologies

Driven by the need for application of portable devices for telecommunications and data processing, at present research and development on improved reflective visual displays takes place everywhere. The large number of suitable physical effects (e.g. electrophoresis – electronic ink, electrical chromism, micro-mechanical electro-optical modulators, etc.), a still larger number of possible combinations of different mechanisms and the common efforts of the researchers and developers should bring to us the desired reflective visual displays with good visual attributes in foreseeable time.

2.1.4. Identification of environments

Within ISO CD 18789-1, WG2 group defined examples of work environments.

• Office	• Laboratory
• Medical	• Education (School, university, library)
• Multi display environments like: control rooms, stock exchange	• Mobile (Car, train, airplane, ship, outdoor)
• Production (industrial)	• Call-/Servicecenter
• Counter	• TV / Radio

Another general environment is the “tele-work” environment. It addresses an activity, which will be exclusive or at times executed at workplaces located out of the central working place area. For this activity telecommunication techniques are used to connect this workplace with the central working place area. Tele work is related to the following environments:

- Home tele-work (home only and/or alternating with office)
- Mobile tele-work (place independent)
- On-site- tele-work
- Tele center

Especially the term „tele-work“ stands for a lot of environments, which may be either stationary in rooms or of mobile nature.

2.1.5. Organization

Since goals must be achieved in an effective and efficient way the organization is of great importance within the work with new technologies. Organization is an answer on questions beginning with words like what, how, where, when, who,.... Organization covers the following aspects:

- Selection of technologies due to variety of tasks (Optimization)
- Useful integration of new systems within already existing systems
- Arrangement of the work (self / time management)
- Training
- Communication

- Availability and acceptance of technologies

2.1.6. Work / Health Protection

This element covers the following aspects:

- Physical work load
- Mental load
- Well-being and health
- Motivation and satisfaction
- Room for manoeuvre and decision

The integration of new visual display techniques into working tools should cover these basic health protection aims.

2.1.7. Resources

The foundation of live is based on clean water and air, sufficient energy, health etc. Energy is the basis for keeping technologies working. Due to limited availability of fossil energy and increasing environmental pollution the energy consumption as well as the environmental compatibility during the whole duration of live of the product should be considered closed to the human factors requirements.

3. Analysis of attributes of the actual context of use

3.1. User

The user can be described by his capabilities and limitations of the visual channel (visual performance), which directly affect design of the visual display. These capabilities and limitations are mostly well known and led to requirements for the displayed information. The natural degeneration of visual performance, caused by the age of humans, shall be considered. The proposed age is 80 years.

3.2. Visual tasks with displays

The activities reading, writing, monitoring, controlling, observing, drawing/painting, presentation can be specified by the following fundamental visual tasks:

a) Perception of structures (pattern) varying in

- brightness
- colour
- shape

with different gradation in

- detail (amount and fineness/accuarcy)
- reality (viewing of virtuality, viewing of reality)

Within the colour space the gradation may be in steps (2 steps, n steps) or continuous.

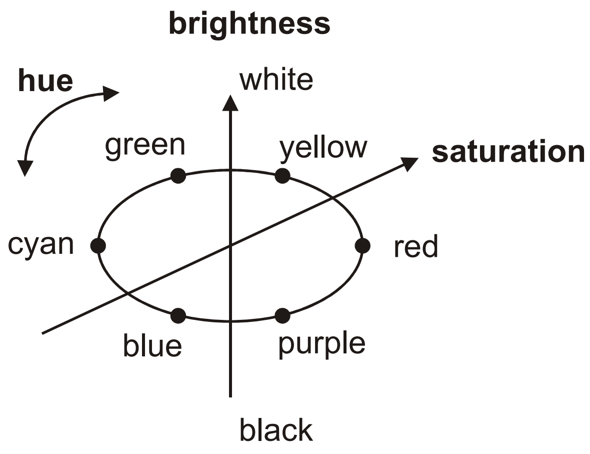


Fig. 3-1 Colour space

Perception is further divided into sub tasks. Hereby definitions for colour detection, colour discrimination, colour identification and colour interpretation are taken from ISO 9241-8 and generalized here:

Detection: Perception of the presence of a visual stimulus on a visually noisy background

Discrimination: Detection of differences between visual stimuli

Identification: Perception signified by the ability to name the structure

Interpretation: Association of a particular visual stimulus to a meaning or function

This report mainly focuses on attributes on the syntactic level. On the syntactic level, the physical design of the visual display with respect to properties of the user, task and environment is considered. Aspects on semantic level, i.e. “is the meaning of a specific information coded adequately?” are not considered in this report.

b) Amount of information

Without scrolling:

- reading/writing e.g.: 1 character, n characters, 1 word, n words, n sentences, processing a size of DIN Ax (x = 9, 8, 7, 6, 5,.....)
- graphic in different sizes
- pictures/photos in different sizes

c) Image type

- (quasi) static
- with motion

d) Viewing conditions

- viewing distance
- viewing direction
- eye and head movement
- single user (with or without privacy)
- multiple user

3.3. Equipment and technology attributes

The equipment consists of several input/output devices or man-machine interfaces, each of them having individual attributes which influence the usability of the equipment. Also specific product configurations are involved. Examples are shown as follows:

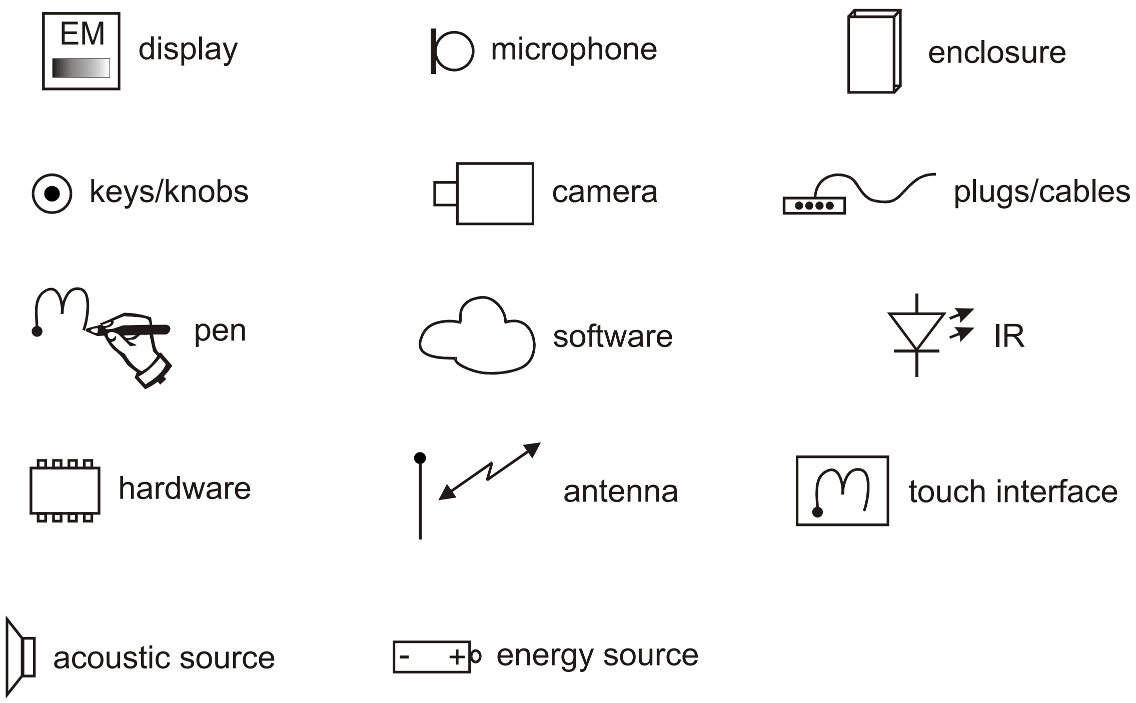


Fig. 3-2 Input/output devices of equipment, specific product configurations

3.3.1. Attributes of the visual display

The attributes of a visual display are described by the physical and optical parameters:

(Display-) Luminance L : Luminance is a photometric, but no psychometric quantity. The photometric definition is given in CIE 17.4/IEC 50, 845-01-35. Luminance allows to distinguish, whether two colour stimuli are of the same brightness. Luminance is the basic quantity being measured at self-luminous visual displays.
(Spectral) Reflectance ρ, $\rho(\lambda)$, R‘, R‘(λ): Ratio of the reflected luminous flux to the incident flux in the given conditions (CIE 17.4/IEC 50, 845-04-58). Reflectance is the basic quantity being measured at non-self luminous visual displays.
Luminous flux Φ : Radiant flux weighted by the V(λ) function (CIE 17.4/IEC 50, 845-01-25). Luminous flux is the basic quantity being measured with front projection devices.
(Luminance-) Contrast CR, C_m : The relationship between the higher and lower luminance that define the feature to be detected, expressed as either contrast modulation or contrast ratio (ISO 9241-3, ISO 13406-2, CIE 17.4/IEC 50, 845-02-47). $C_m = \frac{L_H - L_L}{L_H + L_L}$ $CR = \frac{L_H}{L_L}$
Luminance loading: The luminance of a white area on the screen with black background as a function of the size of the white area (VESA FPDM).
Halation: The luminance of a black area on the screen with white background as a function of the size of the black area (VESA FPDM).
(Relative) spectral distribution S(λ) of useful information of the visual display: Intensity of light at different wavelength (CIE 17.4/IEC 50, 845-01-17, CIE 17.4/IEC 50, 845-01-18).

Colour gamut: Area of the triangle subtended by the primaries red, green and blue in the CIE 1976 uniform-chromaticity-scale diagram expressed as a percentage of the area subtended by the spectrum locus (Brill, Keller). Colours outside the triangle are not reproducible.
Colour tracking: Ability of a visual display to produce the same colour at different drive levels (Keller).
Colour rendering: Effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant (CIE 17.4/IEC 50, 845-02-59). With visual displays: Exact reproduction of chromaticity of non-luminous colours and relative reproduction of luminance. This process is called „colorimetric exact colour rendering“ (Lang).
Colour difference ΔE^*_{uv} : Euclidean distance between the points representing two colour stimuli in the L*u*v* space (CIE 17.4/IEC 50, 845-03-55).
Display gamma γ : Electro-optical transfer function; light output over the complete range of drive signal (EBU Tech. 3273-E, VESA FPDM).
Coding (luminance, colour): • Information presented by temporally independent differences in image luminances or image colours. • Information presented by temporary luminance variations or colour variations. (ISO 9241-3, ISO 13406-2)
Image Polarity: Relationship between background brightness and image brightness (ISO 9241-3). Positive Polarity: dark images on a bright background Negative Polarity: bright images on a dark background
(Screen surface -) Reflection L_r : Radiation returned by a (screen) surface (CIE 17.4/IEC 50, 845-04-42).

Luminance balance: Ratio between the luminances of the displayed image and its adjacent surround, or sequentially viewed surfaces (ISO 9241-3, ISO 13406-2).
Flicker (temporal instability): Perception of unintended temporal variations in luminance (ISO 9241-3).
Jitter (spatial instability): Perception of unintended temporal and spatial variations in images (ISO 9241-3) in other words: small movement of the image or parts of the image displayed on the screen.
Convergence / misconvergence: A white character or graphic element is formed by the overlaid images of the three display colours red, green and blue. Ideally these images exactly coincide. This is called convergence. If these images does not coincide exactly characters or graphic elements get colour fringes. This effect is called misconvergence (ISO 9241-8).
Raster modulation: The relative spatial variation in maximum to minimum luminance when all pixels are switched on (ISO 9241-3).
Pixel, pixel pitch (pixel size): A pixel is the smallest element that is capable of generating the full functionality of a visual display (ISO 13406-2). Pixel pitch: size of the pixel in horizontal as well as vertical direction (ISO 13406-2).
Resolution: Number of pixel used in horizontal and vertical direction to display the information.
Display size: Active area that displays the visual information.
Fill factor: Fraction of the total area geometrically available to a pixel that can be altered to display information (ISO 9241-3; ISO 13406-2).
Font design: Presentation of characters on the screen: e.g. character height, character width, character matrix, character width to height ratio, stroke width, between character/word/line spacing (ISO 9241-3, ISO 13406-2).

Sharpness: Sharpness is related to clearly perceptible edges and the rendition of fine detail in the displayed image.
Response time: Time for the luminance of a visual object to change (ISO 13406-2).
(Spatial-) Uniformity of luminance, reflectance, luminous flux, contrast, colour and character (ISO 9241-3/8, ISO 13406-2, IEC CD 61747-6-2): • Lateral uniformity (i.e. across the viewing-area) and directional uniformity (i.e. as a function of the viewing direction) of luminance, reflectance, contrast and colour. • Lateral uniformity of luminous flux and characters.
Linearity, orthogonality: Geometrical presentation of images on the screen. E.g. uniformity of length of rows and columns, displacement of characters, perpendicularity of rows and columns (ISO 9241-3).
pixel faults: local defects of pixels or sub pixels (ISO 13406-2) local defects of the phosphor layer
Artefacts (unwanted attributes): cross talk: the luminance variation part of a display area produced by the image displayed on another part of the display (IEC 61747-1, Amendment 1) after image: short time remnant of an image on the screen after actual image is removed (IEC 61747-1, Amendment 1) image sticking: long time remnant of an image on the screen after actual static image is removed (IEC 61747-1, Amendment 1)
Stability: Constancy of a parameter (e.g. luminance, luminous flux, colour) over time (short-time or long-term).

3.3.2. Attributes of equipment peripherals and interfaces

Examples (not covered in this report):

Keys and control knobs: e.g. size, contrast of inscription, key displacement and force, keying feedback (ISO 9241-4)
Pen: e.g. size and weight (ISO 9241-9)
Hardware: e.g. operating speed, storage capacity, power consumption
Acoustic source: e.g. frequency response, sound pressure, linearity
Microphone: e.g. sensitivity, frequency response, linearity
Camera: e.g. resolution, sensitivity, zoom, contrast rendering, colour rendering, use at day light/artificial light
Software: e.g. character and object size, luminance and colour coding, resolution
Antenna: e.g. SAR value (specific absorption rate valu)
Energy source: e.g. capacity
Enclosure: e.g. size and weight, shape, gloss of housing, placement of keys/knobs, visibility of the display, dazzling effects of the front/side/back light
Plugs/cables: e.g. transmission rate, signal quality
Infra Red (IR): e.g. transmission range
Touch interface: e.g. accuity

3.3.3. Other characteristics

Examples (not covered in this report):

Robustness: e.g. resistance against environmental conditions
Lifetime: the interval during which a equipment continues to function, longevity
Power consumption: e.g. heat generation
Environmental issues: e.g. harmful substances, recycling, minimizing of used resources (suitability for environment)
Noise emissions: reduction of work load
Radiated emissions: safety and health of the user
Documentation: e.g. completeness, correctness, understandability

3.3.4. Use of equipment

Concerning the of use of equipment there are two further aspects: location of use and type of use:

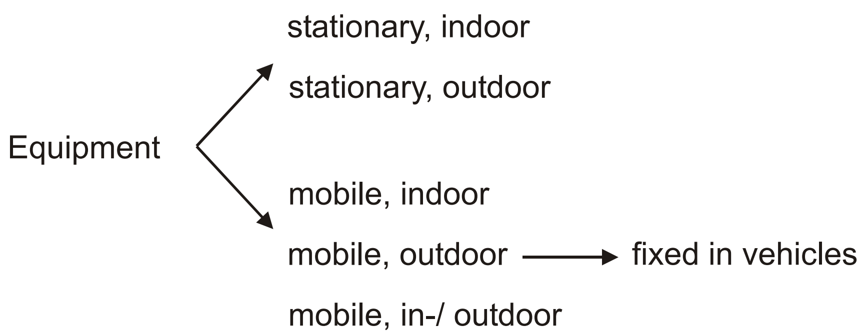


Fig. 3-3 Location of use

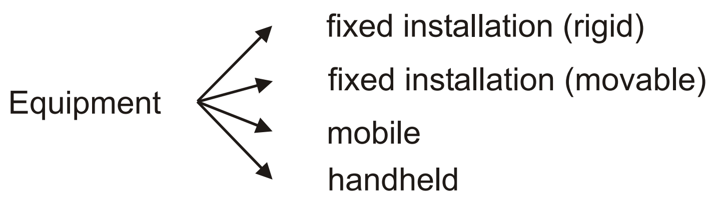


Fig. 3-4 Type of use

3.4. Environment factors

The environment is defined by the following factors:

- illumination conditions (illuminance level E, spectral distribution $S_A(\lambda)$ and the uniformity g)
- climatic conditions (air pressure, wind, temperature, humidity)
- noise
- shock and vibration
- electromagnetic fields
- others
- space

3.4.1. Illumination conditions

a) Illuminance level

The effect of illuminance level is shown in the following figure:

- Different illuminance level from ambient light (natural or artificial sources)
- Luminance from surroundings of different reflectance ρ : $L = \frac{\rho \bullet E}{\pi}$

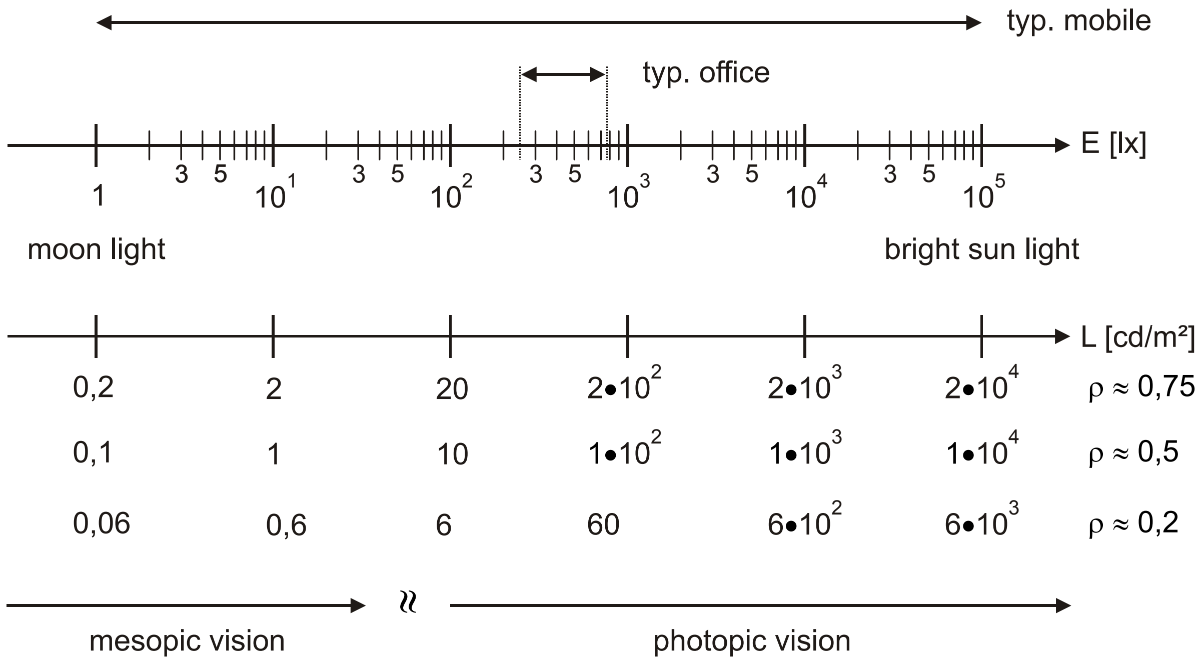


Fig. 3-5 Range of illuminance depending on the use and environment

Environment	Diffuse illumination	Specular illumination
Indoor	$E < 50$ lx 50 lx $\leq E \leq$ 250 lx 250 lx $\leq E \leq$ 750 lx $E = 1000$ lx $E = 2000$ lx $E \geq 5000$ lx	L_A = 125 cd/m² L_A = 200 cd/m² L_A = 2000 cd/m²
Outdoor	1 lx $\leq E \leq 10^5$ lx	Overcast sky: $L_A \approx$ 2000 cd/m² Clear sky: $L_A \approx$ 8000 cd/m² Solar : $L_A \approx 10^9$ cd/m²

Tab. 3-1 Range of illumination depending on the use and environment

b) Spectral distribution and correlated colour temperature

Environment	Illuminant, Correlated colour temperature	
Indoor	A:	T = 2856 K
	Warm white:	$T \leq 3300$ K
	Neutral white:	$3300 \text{ K} \leq T \leq 5000$ K
	Daylight white:	$T > 5000$
Outdoor	Daylight D65	$T \approx 6500$ K

Tab. 3-2 Spectral distribution and colour temperature of environments

c) Uniformity ratio of illuminance (on a given plane)

Uniformity considers the illumination distribution in the environment.

$$g_1 = \frac{E_{min}}{\overline{E}}$$

$$g_2 = \frac{E_{min}}{E_{max}}$$

In case of no uniformity the directionality of illumination has to be specified.

3.4.2. Climatic conditions

a) air pressure: Typically, the air pressure will range between: 860 mbar – 1060 mbar.
b) wind: For indoor use of the equipment wind is normally excluded. Only with outdoor use wind should be considered.
c) Temperature: Typically regions are shown in the following figure.

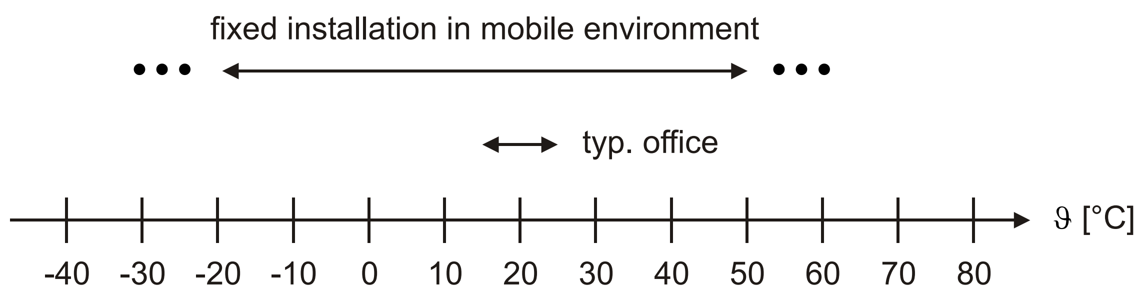


Fig. 3-6 Range of the temperature depending on the environment

d) humidity: Typically, the humidity will range between: 20% – 80%.

3.4.3. Noise

Typically sound pressure level L_{pA} is shown in the following figure.

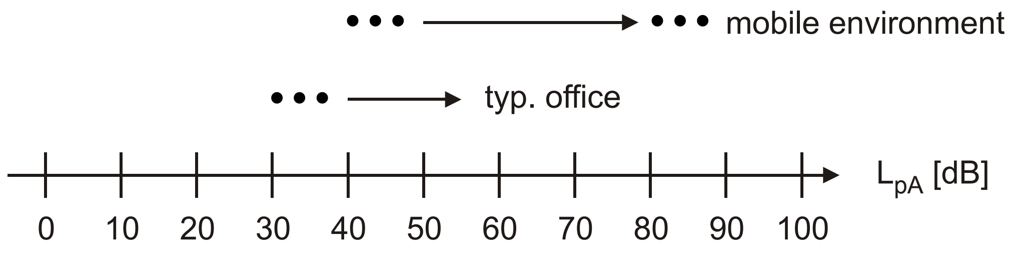


Fig. 3-7 Range of the sound pressure level depending on the environment

3.4.4. Shock and vibration

For stationary use of the equipment shock and vibration is normally excluded. Only with mobile use shock and vibration should be considered (more research required).

3.4.5. Electromagnetic fields

Electromagnetic fields can disturb the displayed information and the operation, like jitter with CRT technology.

3.4.6. Other environment factors

- Dust
- Fog (salt or other chemical substances)

3.4.7. Space

Space is needed to keep the viewing conditions and/or projection distances.

4. Analysis of interdependencies and structure of the standard ISO CD 18789

For a successful human-display interaction, a number of different requirements must be met at the same time in an appropriate balance. This match is of high complexity due to several dimensions and parameters involved and interrelated.

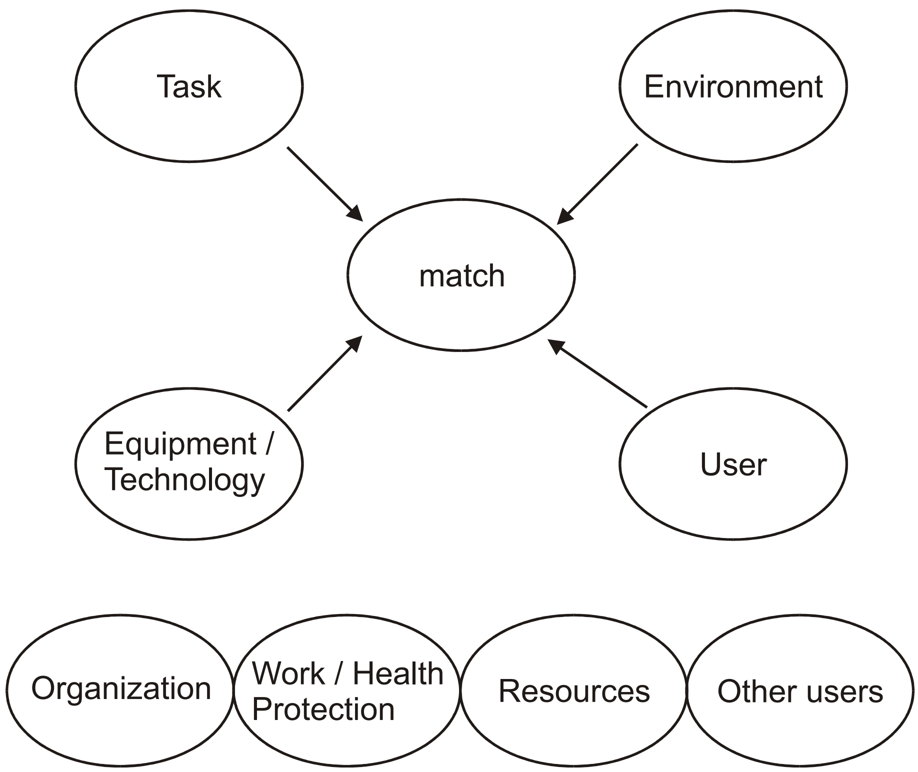
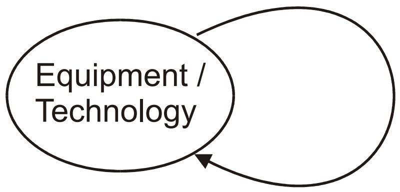


Fig. 4-1 Match of elements

It is required to keep the match of elements under control. If a task and/or environment is defined, a control of attributes from equipment/technology becomes necessary. The basis is the user with his physiological/psychological capabilities and limitations.

As a next step, the meaning of dependence/independence on technology, task and environment is discussed.

4.1. Equipment/Technology



technology dependent means:

a) (visual) attributes inherent to the technology

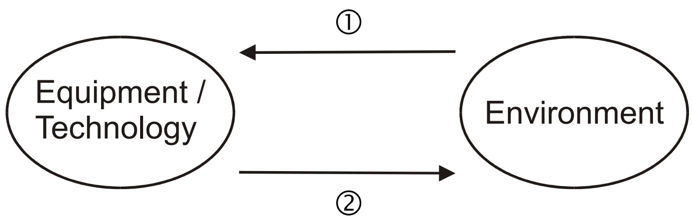
b) Location of use and type of use

technology independent means:

Attributes not determined by the technology.

In practice all attributes introduced in chapter 3.3.1 are determined by the technology. Therefore these attributes are technology dependent.

4.2. Equipment/Technology and Environment



environment dependent means:

a) (Visual) attributes of the technology/equipment are required due to attributes of the environment

b) (Visual) attributes of the technology/equipment are changed due to attributes of the environment

environment independent means:

Attributes of the technology/equipment not changed by the environment.

Note:

Environmental conditions having destructive influences or outside the operating range are not addressed here.

Interdependence between environment and technologic/equipment attributes depending on environmental conditions:

①: The environment is defined. The environment dependent technologic/ equipment attributes must be controlled.

②: The technology/equipment is defined. The environment must be controlled.

Example:

The illumination conditions are of great importance during use of different technologies. This is visualized in the following figure:

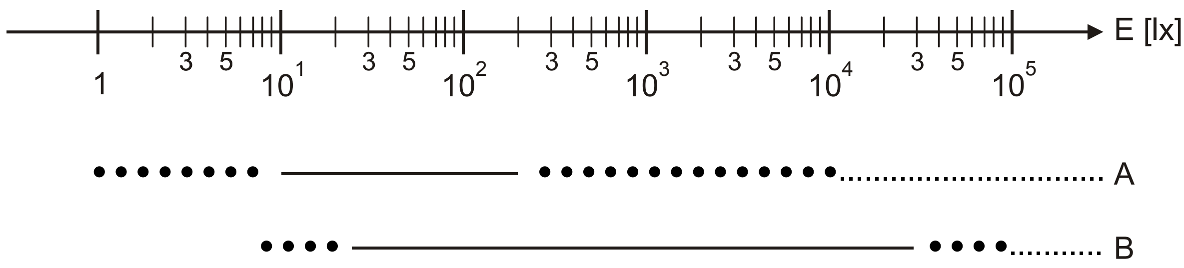


Fig. 4-2 Use of technologies at variable illuminance

“A” stand for self-luminous and projection technologies. The limits of use are:

lower limit: e.g. luminance and contrast must be adjusted

upper limit: e.g. reduction of contrast due to reflection

“B” stand for non-self luminous technologies. The limits of use are:

lower limit: e.g. luminance and contrast too low

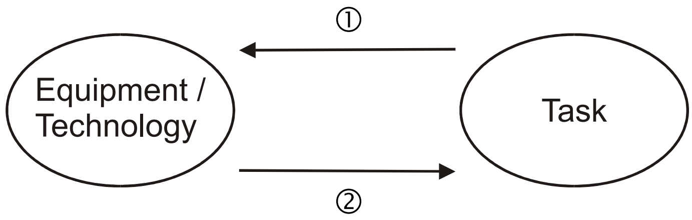
upper limit: e.g. reduction of contrast due to reflection

The following attributes introduced in chapter 3.3.1 are identified as environment dependent:

Attribute	**Context of use**
(Display-) Luminance L	$L = f(E, L_A)$ see chapter 5.3
(Intended Display-) Reflectance ρ , R	Simplified: $L = f(E, L_A) = \frac{\rho_{panel} \cdot E}{\pi}$
Luminous flux Φ	$L = f(E, L_A) = \frac{\rho_{screen} \cdot E}{\pi} = \frac{\rho_{screen} \cdot \Phi}{\pi \cdot A}$
(Luminance-) Contrast CR	$CR = f(E, L_A)$ see chapter 5.2
Spectral distribution $S(\lambda)$ of useful information of the visual display	Match between $S(\lambda)$ and spectral sensitivity of receptors in the human eye
Colour gamut	Colour gamut $= f(E, L_A)$
Colour rendering	$R_a = \sum_{i=1}^{n} R_i$ and $R_i = 100 - 4{,}6 \cdot \Delta E_i$ $\Delta E_i = f(E, L_A)$
Colour difference ΔE^*_{uv}	$\Delta E = f(E, L_A)$
Display gamma γ	$\gamma = f(E, L_A)$
Coding	Coding $= f(E, L_A)$
Image polarity	Image polarity = $f(L_r)$
(Unwanted screen surface -) Reflection L_r	$L_r = f(E, L_A)$
Luminance balance	$L_{Display}$ versus $L_{surround}$
Flicker	Reflected luminance in flicker evaluation (energy in the temporal frequency E_{obs})
Jitter	Produced by external alternating magnetic fields
Pixel pitch	Pixel pitch = f(adaption) = $f(E, L_A)$
Font design (Character height ψ)	$\Psi = f(E, L_A)$
Uniformity	Uniformity $= f(E, L_A)$
Stability	Stability $= f(\vartheta)$

All other attributes introduced in chapter 3.3.1 are identified as environment independent.

4.3. Equipment/Technology and Task



Attributes of the technology/equipment do not depend on the task, since the task does not alter the attributes. But the task leads to requirements which determine the attributes. It is possible to differentiate between:

a) optimization of intended attributes

b) minimization of unintended attributes

Independent from task minimum requirements have to be fullfilled to keep the visual display visual perceptible.

Interdependence between task and technologic/equipment attributes depending on the task:

①: The task is defined. The equipment/technology must be controlled.

②: The equipment/technology is defined. The task must be controlled.

Examples:

Text processing ↔ display size

Graphic Design ↔ e.g. colour rendering

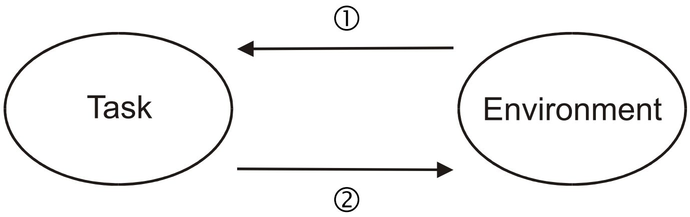
Medical diagnostic (e.g. X-ray images) ↔ e.g. greyscale, pixel faults

Following the interdependence of the attributes introduced in chapter 3.3.1 to the context of use is shown:

Attribute	**Context of use**
(Display-) Luminance	Visual acuity (sharpness), colour perception, glare
(Intended Display-) Reflectance	See (Display-) Luminance and (Luminance-) Contrast
Luminous flux	See (Display-) Luminance
(Luminance-) Contrast	Legibility, level of reality, reproduction of images, fidelity (see Display gamma)

Luminance loading	Unintended attribut
Halation	Unintended attribut
Spectral distribution S(λ) of useful information of the visual display	Detection of information, Reproduction of images
Colour gamut	Reproduction of images, fidelity
Colour tracking	Reproduction of images, fidelity
Colour rendering	Reproduction of images, fidelity
Colour difference ΔE^*_{uv}	Discrimination between colours
Display gamma γ	Tone scale reproduction, fidelity
Coding	Discrimination
Image Polarity	Adaption of the human eye, legibility
(Screen surface-) Reflections	Unintended attribut
Luminance balance	Readaption of the human eye
Flicker	Display size, viewing condition
Jitter	Viewing condition
Misconvergence	Viewing condition
Raster modulation	Unintended attribut
Pixel pitch	Fineness/accuracy of the image
Resolution, Display size	Amount of information shown
Fill factor	Viewing condition
Font design	Legibility, attractiveness
Sharpness	Legibility, attractiveness
Response time	Type of the image shown
Uniformity of luminance, reflectance, luminous flux, contrast or colour	Detection, discrimination, attractiveness
Character uniformity	Viewing condition, Detection Discrimination, attractiveness
Linearity/Orthogonality	Interpretation of the displayed information
Pixel faults	Interpretation of the displayed information
Artefacts	Unintended attributes
Stability	Interpretation of the displayed information

4.4. Task and environment



For the inter-relationship of task and environment, the following applies:

①: The task is defined. The environment dependent attributes must be controlled.

②: The environment is defined. The task must be controlled.

Example:

Check of television pictures	↔	illumination of the environment
Medical diagnostic (e.g. X-ray images)	↔	illumination of the environment

4.5. Structure of the standard ISO CD 18789

Due to above mentioned inter-relationship general recommendations must be defined independent from technology, task and environment. This main thought is also mentioned in Part 3 of ISO CD 18789. Direct evaluation of general recommendations is not possible. Evaluation is possible if the (intended or actual) context of use is known. Therefore the term “requirement” should be renamed to “recommendation” in Part 3 of ISO CD 18789.

Several questions arise:

4.5.1. How to generate and how to describe general recommendations?

The following procedure is proposed:

Step 1: point out the dependency on technology *), task and environment

Step 2: describe effect and/or meaning

Step 3: definition of the general recommendation [common and without reference to technology, task and environment (have a separation)]

*) Note:
All properties mentioned in chapter 3.3.1 depend on the technology. This must not be mentioned in every case.

Example: According to ISO 9241-8 chapter 6.3 Misconvergence is defined as:

„The level of misconvergence at any location on multicolour, shadow mask CRT screens shall not be greater than 3,4 minutes of arc and preferably should be less than 2,3 minutes of arc at the design viewing distance.
Notes:
1) The convergence of electron beams is a major component in the appearance, quality and resolution of a CRT image. Convergence is especially important when resolution is critical, such as when reading alphanumeric characters.
2) If the electron beams are not correctly aligned (i.e., they are misconvergent) on the phosphor triads, they cause the appearance of colour fringes or double images along the edges of an image. Since these fringes reduce image resolution, they can reduce user performance.
3) The lower value of misconvergence (that is, 2,3 minutes of arc) is noticeable, but not visually distracting.
4) As the distance between the viewer and the visual display decreases, the ability of the operator to detect misconvergence increases. Red-green beam misconvergence is the most perceivable of the beam combinations. For line width of 1 to 2 minutes of arc, as little as 0,5 minutes of arc of red-green beam misconvergence is detectable. Blue-green beam misconvergence, the least perceivable of the beam combinations, is detectable at slightly over 1,0 minutes of visual arc.“

Discussion:

Misconvergence is a technology dependent quantity and is related to shadow mask CRT screens. Misconvergence may also occur in projection systems. Misconvergence causes the appearance of colour fringes and reduces the sharpness of the image. Misconvergence depends on the task, due to the viewing distance involved. In general misconvergence shall be reduced. In addition misconvergence does not depend on environmental conditions.

The general recommendation may look as follows:

Misconvergence

Misconvergence does not depend on the environmental conditions. Misconvergence causes the appearance of colour fringes or double images along the edges of an image. At greater levels of misconvergence, users will notice that characters or graphic elements appear blurred. Since these fringes reduce image resolution, they can reduce user performance. Misconvergence shall be reduced below visually distracting values.

Further general recommendations are proposed:

(Display-) Luminance

Luminance depends on the environmental conditions. It is a fundamental quantity to perceive the image. Luminance influences the visual acuity (sharpness), the colour perception and glare. Depending on the environment display luminance shall be sufficient or compatible to the luminance from environment (see also “Luminance balance”). Where applicable display luminance shall be adjustable.

(Intended Display-) Reflectance

Reflectance depends on the environmental conditions. It is a fundamental quantity to perceive the image and details of the image. Reflectance shall be sufficient in order to produce a sufficient luminance and contrast (see also (Display-) Luminance and (Luminance-) Contrast).

Luminous flux

Luminous flux depends on the environmental conditions. Luminous flux is a fundamental quantity to perceive the image. Luminous flux shall be sufficient in order to produce a sufficient luminance (see also (Display-) Luminance).

(Luminance-) Contrast

Contrast depends on the environmental conditions. It is a fundamental quantity to perceive details of the image. Contrast influences the legibility and reproduction of images. Contrast shall be sufficient. Where applicable contrast shall be adjustable.

Luminance loading

Luminance loading does not depend on the environmental conditions. It produces non-uniformity of luminance and possible unintended coding. Luminance loading shall be reduced below visually distracting values.

Halation

Halation does not depend on the environmental conditions. It reduces the contrast of the visual display. Halation shall be minimized.

Spectral distribution (of useful information of the visual display)

Spectral distribution depends on the environmental conditions.

a) It influences the colour appearance. See also “Colour Gamut”.
b) Since sensitivity of the human eye varies with the state of adaption [$V(\lambda) \leftrightarrow V'(\lambda)$] spectral distribution shall match.

Colour gamut

Colour gamut depends on the environmental conditions. It influences the reproduction of colours. Colour gamut shall be sufficient. Chromaticity coordinates of primaries and their tolerances shall be specified.

Colour tracking

Colour tracking does not depend on environmental conditions. Its effect is stability of chromaticity coordinates of the primaries independent from drive signal. Colour tracking shall be sufficient.

Colour rendering

Colour rendering depends on the the environmental conditions. It influences the identification and interpretation of displayed information. Rendered colours shall appear as intended or natural. The user shall have a correct impression of rendered colours. Therefore colour rendering shall be sufficient.

Colour difference ΔE^*_{uv}

Colour difference depends on the environmental conditions. It is used to discriminate between colour pairs. Colour difference shall be sufficient.

Display gamma

Display gamma depends on the environmental conditions. Display gamma influences the gradation of greyscales/colour scales, the contrast and the reproduction of images. Display gamma shall be ascending monotonous and sufficient smooth.

Coding

Coding depends on the environmental conditions. It means temporally independent differences in image luminances or colours as well as temporary luminance variations or colour variations. Coding shall be sufficient by using either sufficient luminance ratio, colour difference, timing, object size and/or object shape.

Image Polarity

Image polarity depends on the environmental conditions. Either positive image polarity (dark images on a bright background) or negative image polarity (bright images on a dark background) is acceptable. If a visual display provides both image polarities, it shall meet all requirements for each image polarity.

(Screen surface-) Reflections

Reflections depend on the technology (use of the equipment) and on the environmental conditions. Reflections reduce the contrast and therefore the legibility. In addition they reduce the saturation and change the hue. Unwanted reflections shall be minimized.

Luminance Balance

Luminance balance depends on the environmental conditions. Luminance balance is the ratio between the luminances of the displayed image and its adjacent surround, or sequentially viewed surfaces. Therefore luminance balance will influence the adaption of the human eye. To avoid unnecessary readaption the ratio shall be well-balanced.

Flicker

Flicker depends on the environmental conditions. Flicker causes eyestrain and shall be reduced below recognizable values.

Jitter

Jitter depends on the environmental conditions. Jitter reduces the sharpness and causes eyestrain. Jitter shall be reduced below recognizable values.

Raster modulation

Raster modulation does not depend on the environmental conditions. Raster modulation reduces the resolution and uniformity of characters or graphic elements. Raster modulation shall be reduced below visually distracting values.

Pixel pitch

Pixel pitch depends on the environmental conditions. It influences the fineness of the displayed image. Pixel pitch shall be suitably small.

Resolution

Resolution does not depend on the environmental conditions. Resolution is the relation between pixel pitch and display size. Resolution shall enable a satisfying reproduction of the original image. See also “Display size”.

Display size

Display size does not depend on the environmental conditions. It influences the amount of information shown on the visual display. Display size shall be sufficiently large.

Fill factor

The fill factor does not depend on the environmental conditions. In case of low pixel density, formulated in terms of visual angle, a low fill factor will cause interruption of displayed information. Therefore fill factor shall exceed a minimum value.

Font design

Font design depends on the environmental conditions. Font design shall be sufficient for good legibility and attractiveness.

Sharpness

Sharpness does not depend on the environmental conditions. Reduced sharpness causes eyestrain due to loss of clearly perceptible edges. Also fine details may not be rendered (washout). The smallest picture element shall be displayed sharp.

Response time

Response time does not depend on the environmental conditions. Insufficient response time causes blured or jerky images and reduce the contrast. Response time shall be short enough for the type of information shown.

Uniformity of luminance, reflectance, luminous flux, contrast or colour

Luminance uniformity, uniformity of reflectance, uniformity of luminous flux, contrast uniformity or colour uniformity depends on the technology (use of the equipment) as well as on the environmental conditions. Non-uniformity reduces the detection and discrimination of the displayed information and the attractiveness. Luminance, reflectance, luminous flux, contrast or colour shall be uniform.

Character uniformity

Character uniformity does not depend on the environmental conditions. Non-uniformity reduces the detection and discrimination of the displayed information and the attractiveness. Characters shall be uniform.

Linearity/Orthogonality

Linearity/Orthogonality does not depend on the environmental conditions. Non-linearity/orthogonality causes distorted images and non-uniformity of geometric objects. Non-linearity/non-orthogonality shall be reduced below visually distracting values.

Pixel faults

Pixel faults do not depend on the environmental conditions. Pixel faults cause unintended information and therefore misinterpretations. Pixel faults shall be minimized.

Artefacts

Artefacts do not depend on the environmental conditions. Artefacts reduce perceived image quality and therefore shall be reduced below visual distracting values.

Stability

Stability depends on the environmental conditions. Instability may cause misinterpretations. Geometric and photometric visual display attributes shall be stable.

4.5.2. Ergonomic design principles

As a next step the ergonomic design principles behind those general recommendations have to be identified within the standardization work. Proposed examples are:

- Detectability
- Legibility
- Discriminability (on syntactical level)
- Consistency

as introduced in ISO 9241-12.

4.5.3. How to group general recommendations with attributes from task, environment, equipment/technology and user?

For structure and design of ISO CD 18789-7 the following considerations are proposed:

a) Classification of different references as intended context of use:

- Classification of different type of users
- Classification of different environments and their attributes
- Classification of different tasks
- Classification of the use of technologies

b) For each technology:

- Check on applicability for each general recommendation due to the technology
- Specification of user dependent requirements
- Specification of environment dependent requirements
- Specification of requirements due to the task
- Specification of requirements due to the use of the technology

under consideration of the laboratory test and evaluation methods

4.5.4. Effects of the proposed structure

A new technology shall be added → Proceeding?

A new equipment peripheral/interface shall be added → Proceeding?

The following considerations are proposed:

- Analysis of attributes of the user with respect to the technology or equipment peripheral/interface
- Analysis of tasks
- Analysis of attributes of technology
- Analysis of environment attributes
- Evaluation of general recommendations
- Identification of design principles
- Grouping of attributes from task, environment, equipment/technology and user

5. Basic concepts for insuring visual perception

5.1. Illumination conditions

The typical use of a visual display is illustrated in the following figure. Elements of vision are symbolically drawn:

- Different illumination conditions (natural, artificial sources) and their attributes
- Surrounding, which also affects the adaption of the eye
- The display with its attributes
- The eye with its attributes

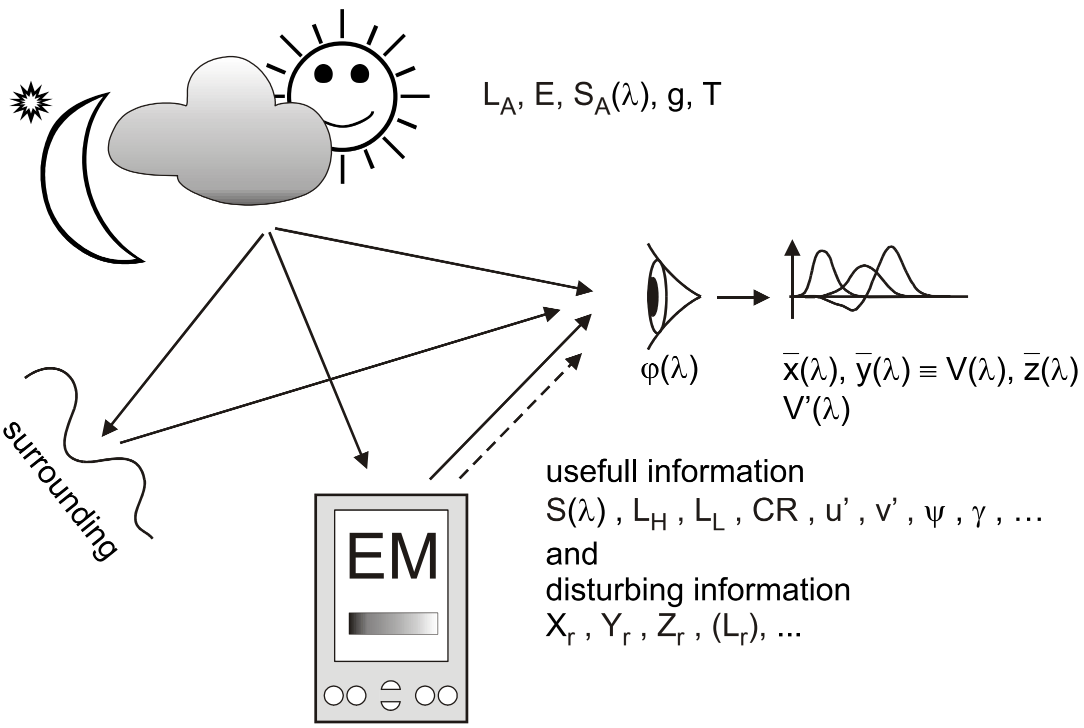


Fig. 5-1 Use of visual displays

By the visual display useful information is given for the user based on:

- Luminance L_H
- Contrast $CR = L_H/L_L$
- Colour contrast ΔE

Due to reflection the different illumination conditions result in disturbing information. Consequences of disturbing information are:

- Reduction of contrast

$$CR = \frac{L_H + L_r}{L_L + L_r}$$

- Desaturation and change of hue

$$\Sigma X = X + X_r$$
$$\Sigma Y = Y + Y_r$$
$$\Sigma Z = Z + Z_r$$

Usefull information is recognizable if the following conditions are met:

- useful information must have a minimum luminance
- useful information must have a minimum contrast
- useful information must have a minimum size
- adaption of the eye to current luminance of field of vision
- sufficient time of presentation of the object
- reduction of unintended information so that the perception of useful information is not influenced and given

5.2. (Luminance-) Contrast CR

A comparison of different contrast requirements from ISO 9241-3 and ISO 13406-2 is shown in the following figure.

- Minimum contrast according to ISO 9241-3: $CR = 3:1$
- Minimum contrast according to ISO 13406-2: $CR = 1 + 10 \bullet L_L^{-0,55}$

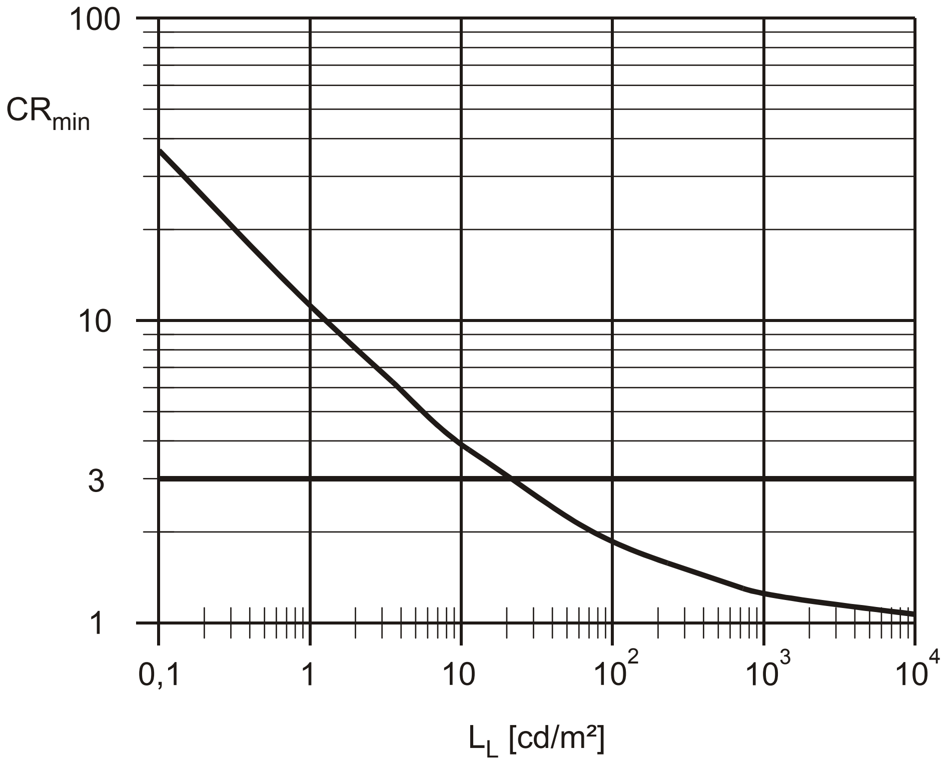


Fig. 5-2 Minimum contrast of visual displays according to ISO 9241-3 / ISO 13406-2

Comparison and discussion:

a) both curves cross at $L_L^* \approx 18{,}7$ cd/m²

b) below L_L^* : requirement of ISO 9241-3 is too small when compared to ISO 13406-2

c) above L_L^* : requirement of ISO 9241-3 is too high when compared to ISO 13406-2

d) contrast according to ISO 13406-2 strives to 1 with increasing L_L

Due to different contrast requirements within ISO 9241-3 and ISO 13406-2 another contrast requirement is discussed and proposed here:
Based on historical research, Kokoschka did a mathematical evaluation of the visual contrast threshold $\overline{C}$. He gave a mathematical expression of $\overline{C}$ as a function of luminance L_L and angular extend α of the visual target:

$$\overline{C} = \frac{L_H - L_L}{L_L} = f(L_L, \alpha)$$

$$\overline{C} = \overline{C}_{min} \bullet f_1 \bullet f_2$$

$$\overline{C} = 0{,}00275 \bullet f_1 \bullet f_2$$

with

$$f_1 = 1 + \left(\frac{L_L}{0{,}158}\right)^{-0{,}484}$$

$$f_2 = 1 + \left(\frac{\alpha_0}{\alpha}\right)^2$$

$$\alpha_0 = 7{,}5 + 133 \bullet \left(1 - \frac{1}{1 + \left(\frac{L_L}{0{,}00075}\right)^{-0{,}383}}\right)$$

This expression is converted to CR:

$$CR = \frac{L_H}{L_L} = 1 + \overline{C}$$

Depending on the size of the visual target the visual contrast threshold $\overline{C}$ must be adjusted by a constant k. Using an object size of α = 1‘ will lead to a constant k of:

$$CR = \frac{L_H^*}{L_L^*} = 3 = 1 + k \bullet \overline{C}(L_L^* \approx 18{,}7 cd/m^2; \alpha = 1')$$

$$k \approx 6{,}3$$

In general:

$$CR = \frac{L_H}{L_L} = 1 + 6{,}3 \bullet \overline{C}(L_L; \alpha = 1')$$

The result is shown by dotted line in the following figure:

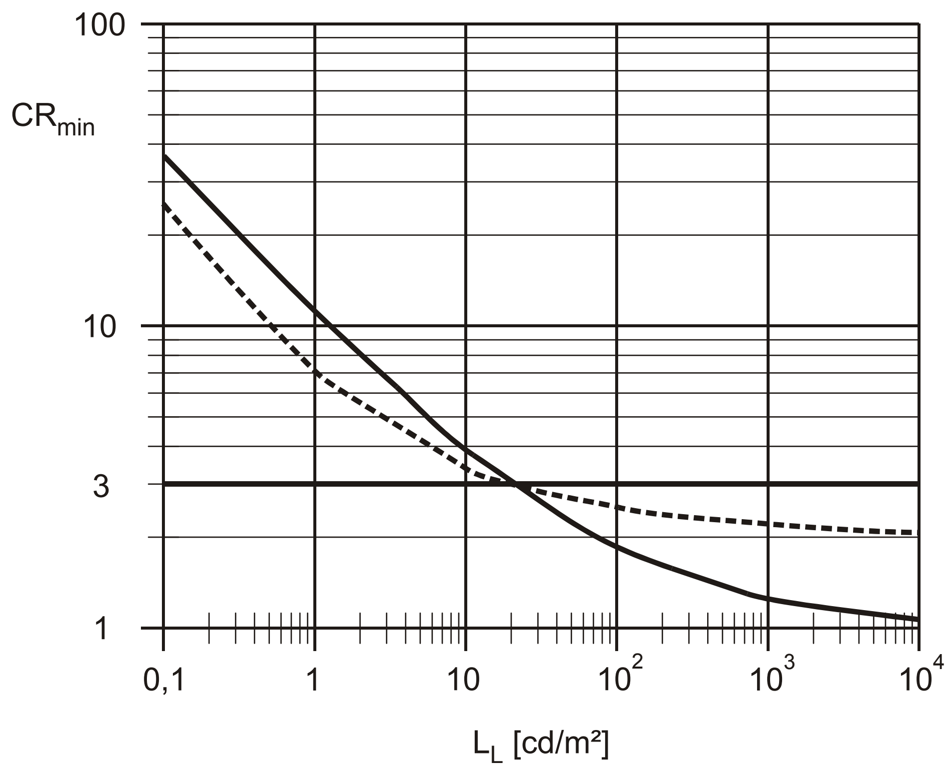


Fig. 5-3 Minimum contrast of visual displays

Due to different requirements between ISO 9241-3 and ISO 13406-2 the (adjusted) visual contrast threshold for an object size of 1‘ is suggested as the minimum contrast requirement for electronic visual displays. A sufficient approximation will be:

$$CR_{min} = 2{,}2 \bullet (1 + 2{,}2 \bullet L_L^{-0{,}65}) = 2{,}2 + 4{,}84 \bullet L_L^{-0{,}65}$$

Basic data for above mentioned contrast requirement were derived by experiments on young observers. Required (Luminance-) contrast CR differs with age of the users. Therefore the introduction of a contrast multiplier k_{age} is suggested by Blackwell:

$$CR_{min,age} = k_{age} \bullet CR_{min}$$

Age of the user [years]	contrast multiplier k_{age}
20	1,00
25	1,00
30	1,02
35	1,07
40	1,17
45	1,34
50	1,58
55	1,90
60	2,28
65	2,66

5.3. (Display-) Luminance

Apart from L_H, L_L the luminance L_r reflected from visual display or screen surface must be considered in illuminated environments. L_r considers the luminance components L_D and L_S:

L_D: diffuse reflected luminance $L_D = q \bullet E = R_D^{'} \bullet E$

L_S: specular reflected luminance $L_S = R_S^{'} \bullet L_A$

In general the contrast will be:

$$CR_{min} = \frac{L_H + L_D + L_S}{L_L + L_D + L_S} = 2{,}2 + 4{,}84 \bullet (L_L + L_D + L_S)^{-0{,}65}$$

Solving this equation to L_H the minimum display luminance L_{Hmin} is derived:

$$L_{Hmin} = \left(2{,}2 + 4{,}84 \bullet (L_L + L_D + L_S)^{-0{,}65}\right) \bullet (L_L + L_D + L_S) - L_D - L_S$$

Therefore: L_{Hmin} is a function of

- L_L
- $L_D = q \bullet E = R_D^{'} \bullet E$
- $L_S = R_S^{'} \bullet L_A$

This is illustrated in the following two examples:

Example 1

typical CRT monitor as used in offices with:

$L_L = 0{,}5\ cd/m^2$

$q = \frac{\rho}{\pi} \approx 2{,}5\%$

$L_A = 0\ cd/m^2$

E [lx]	L_{Hmin} [cd/m²]
1	≈ 5
10	≈ 6
100	≈ 11
1000	≈ 46
10000	≈ 334
100000	≈ 3075

Example 2

typical Laptop with TFT-LCD with:

$L_L = 0{,}5\ cd/m^2$

$q = \frac{\rho}{\pi} \approx 0\%$

$R_{S-EXT} \approx 2\%$

L_A [cd/m²]	L_{Hmin} [cd/m²]
1	≈ 5
10	≈ 6
100	≈ 10
1000	≈ 39
10000	≈ 272
100000	≈ 2470

Lower limit for L_{Hmin} :

To perceive coloured images a minimum luminance L_{Hmin} of 3 cd/m² is required (Lange). In case of low illuminance L_{Hmin} is also a function of the display size. As an example in cinemas L_{Hmin} shall be 35 cd/m² and preferably 50 cd/m² (ISO 11315-2).

Upper limit for L_H :

Glare (disability glare or discomfort glare) shall not be produced by the visual display. Glare depends on the state of adaption of the human eye.

5.4. Interdependence between geometric proportions of the visual display, displayed information and viewing conditions

While looking to a visual display at a viewing distance d_{view} the following geometric proportions are noticeable:

- Pixel size
- Character size
- Display size

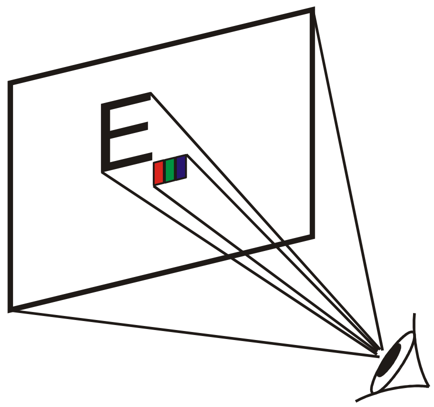


Fig. 5-4 Geometric proportions

The following figure shows the interdependencies between geometric proportions of the visual display, displayed information and viewing conditions as well as influences from task and environment:

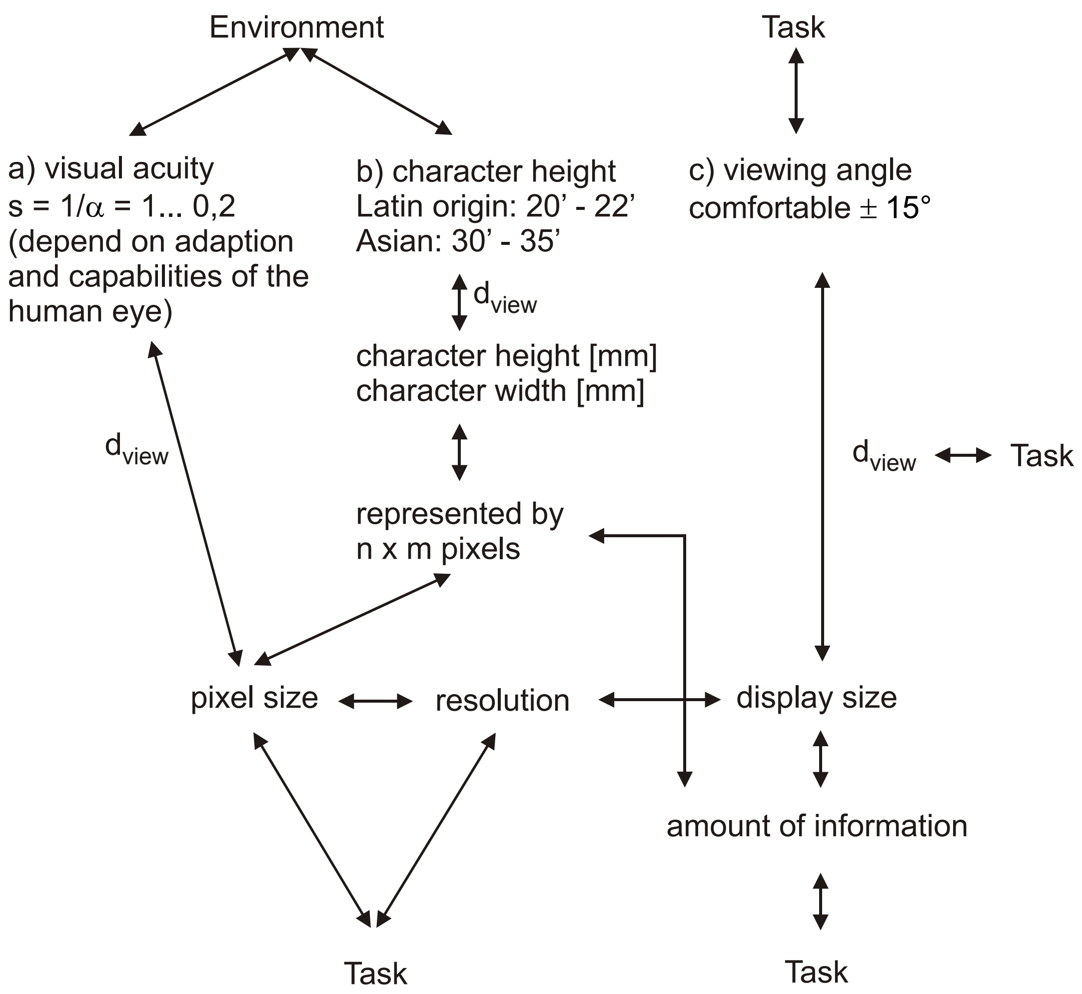


Fig. 5-5 Roadmap between geometric proportions and viewing conditions

If resolution increases in case of a fixed display size the pixel size will decrease. As a result fineness is increasing. To keep character size stable its representation by n x m pixels must increase.

Display size and pixel size are adjustable during development of new visual displays. Due to miniaturization of visual displays respectively the pixel size standardization work should give sufficient support to keep displayed information legible.

6. Acknowledgment

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