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Digital Medical Diagnostic Displays

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Abstract— **Digital medical imaging technology is developing rapidly in the last few decades and widely used as medical diagnostic tool. Medical image visual content analysis and interpretation is the most often method applied in detection and tracking of the pathogen behaviour of the imaged tissue. The human visual perception of the displayed image is limited by human visual system properties, display device characteristics and illumination environment influences during observation. In this review article we are analyzing how medical image specificities, human eye visual properties and display technology ultimate performances could be used to define medical image monitor technical requirements according to named application. We are focused on the analysis of the physical processes involved and technical aspects leading to optimization of the medical display requirements definition. This will help engineering and medical specialists to understand better medical display properties and provide more objective assessment of the display diagnostic suitability.**

Keywords-Digital medical imaging, displays, brightness, grayscale display function, luminance, display performance parameters, resolution, quality assesment, requirement definition, human visual system, perception of visual information

I. INTRODUCTION

The imaging technology, followed by information technology development over the past 50 years, has facilitated the development of digital medical imaging. This development found important applications in X-ray radiography, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Single Photon Emission Computed Tomography (SPECT) and the Positron Emission Tomography (PET), ultrasound imaging, infrared imaging and optical imaging including video-endoscopies, microscopy, etc. [1]-[5]. The new technologies raise important questions concerning optimization of the acquisition, compression, storage, transfer, and display of the image. Additional image processing algorithms are developing to support medical image interpretation automatization through computer-aided detection (CADe) and diagnosis (CADx). In that case, systematic and objective evaluation of the entire imaging system, from hardware to human interpretation of images, to image quality, is critical. In some cases medical images contain enormous amount of data that need to be processed or compressed to be transferred or stored. Compression algorithms should be designed and validated to provide minimal loss of data. The human visual system limitations are the basic filter used to define how much compression is good enough. In any case human (radiographer) interpretation is the key step for the diagnosis using presented medical images.

One of the most important problems is selection of appropriate display media for presentation of the digital medical images. The developments in the area of display technologies are intensive providing various display technologies [6]-[12] suitable for visual data presentation. Display screen properties have a key influence on the presented image quality [13]-[16].

The selection of related display technology depends on display ultimate performances, human visual system (HVS) limitations and medical image specificities. Image quality requirements depend on the digital imaging system application.

The comparative studies on the influence of various display technologies and display properties conducted during medical display quality assessment standards [16-19] development provided a basic technical knowledge supporting digital medical displays quality understanding.

The purpose of this article is to provide basic information about processes and factors influencing image quality. Only systematic and objective evaluation of the entire imaging system chain - from hardware to human interpretation of images could provide sufficient diagnostic quality assessment. Actually, diagnostic quality depends on presented digital image quality and quality of the human operator interpretation. Pathological condition interaction with imaging radiation source determines the information which must be used as medical data. This information should be sufficiently contrasted with the surrounding tissue. Diagnostic quality is therefore highly dependent on both processes: respective imaging data gathering technique and concerned pathological condition recognition in the image presented. Because of that the evaluation of medical images diagnostic quality is complex even more complex than simple image quality parameter [20].

In this review article we are analyzing how medical image specificities, human eye visual properties and display technology ultimate properties influence medical image monitor technical requirements definition according to named application. The goal is to provide equally good understanding

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This paper is a revised and expanded version of the paper presented at the XIX International Symposium INFOTEH-JAHORINA 2020, [61] of the optimization problem for engineering and medical specialists in the same time. In addition, we are presenting basic set of the selected data that could be useful for both sides. Our findings are based on the review of selected references. These references are selected to refer information source providing more deep understanding of the particular issue and to acknowledge key contributors in the same time.

Medical display evaluation methodologies cover a broad range of methods, from subjective assessment including the widely used Receiver Operating Characteristic (ROC) techniques that measure diagnostic accuracy using experimental data statistical processing methods, to objective assessment, using specially generated test images and metrics such as Just Noticeable Difference (JND) models based on human visual system perception and model observers. The medical image presentation on the workstation display surface is included in all assessment methods, so it is important to understand display optical properties. There is a lot work done to define medical digital image presentation standards providing sufficient diagnostic quality [11-20].

We will discuss only some aspects of the design of medical imaging workstations leading to optimal image interpretation by human observer, to find an answer what display characteristic should be required to prevent display generated medical image degradation. Also, some selected properties of the medical images and human visual system limitation are presented as a lead to workstation technical requirement definition. This could be useful to both sides: display designer and display user (radiographer).

The specificities of the digital medical images are discussed as starting point. Human visual system basic properties and visual data perception limitations are presented as a basis for display ultimate performances definition. The short review of the available and competitive image display technologies are reviewed to provide data regarding display technology limitations and key requirements definition. The medical display image quality assessment standards and techniques are described.

II. SPECIFICITIES OF MEDICAL IMAGES

The generalized diagram of the medical imaging system is presented in Fig. 1. The various radiation sources, imaging sensors and physical processes in the interaction of radiation with tissue eventually having pathological conditions, provide diversified digital images. These images should be additionally processed to be presented to qualified observer.

The image information content and basic properties depends of whole imaging chain characteristics so they could to differ significantly (black and white or color, different size and resolution, etc.). Anyhow, it is important to present images to human observer providing minimal degradation. Originally diagnostic images were recorded on the film, but nowadays they could be recorded electronically and presented using display devices.

Image presentation and operator visual perception depends on several influencing factors as illustrated in Fig. 2. Image display device and its working conditions should be selected to provide optimal viewing and relevant data extraction.

The image display could differ significantly according to the type of data they are providing. The most demanding requirements should be derived from image reading condition defined for film based radiographic (especially mammography) systems, as high demanding.

Reading conditions defined for reading room, and image display parameters defined for light box (backlight) for film reading are key lead for display optical properties definition.

Light-box considerations include luminance, spectral quality, uniformity, and masking. A luminance of minimum 3,000 cd/m2 is recommended for screen film images. Common film size formats are 18 by 24 cm (about 8 by10 in) and 24 by 30 cm (about 10 by 12 in) or higher. The film could to provide black level with optical density- OD about 3, means that film could to provide contrast of about 1000:1.

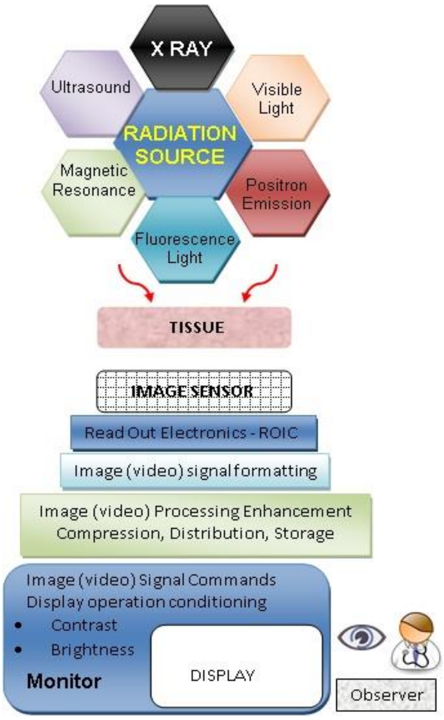

Figure 1. Medical Digital Imaging Chain

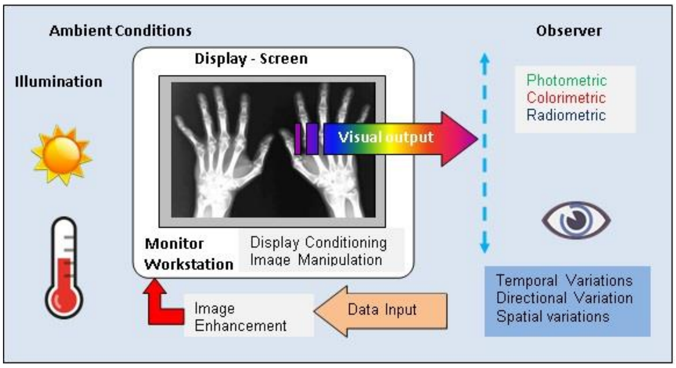

Figure 2. Factors influencing perception of display visual stimulus

According to medical image content and application of the medical imaging system one can to distinguish three types of medical images:

- *diagnostic image*s (the most demanding and providing high image quality defined by standards)
- *clinical review images*- informative images and video presenting content for fast consulting purposes

- *educational (sharing) images* distributed as addition to other data and information.

In the medical diagnostic images contrast distribution is more important than detection of the small details (image resolution)

Only display presenting diagnostic images are usually treated as medical diagnostic devices having properties that should to follow requirements defined in the specific standard. All other display should follow general information display requirements adjusted for specific application.

III. HUMAN EYE VISUAL PROPERTIES

Performance parameters of human vision are the key limiting factor for perception and extraction of information contained in the medical image. The visual information perception by human observer could be used directly for image quality assessment through psychophysical measurements. Psychophysical measurements of the image quality are too costly and time consuming for evaluation of the impact that each algorithm modification might have on image quality. On the other hand, it is convenient to have analytical model of the human vision system to be incorporated in various algorithms for image compression or processing.

Vision scientists measure and quantify human sensory and perceptual capacities. They bring people (usually called subjects or observers) into the laboratory, and use well-controlled physical stimuli and sophisticated behavioral, or psychophysical, techniques to measure their visual capacities. The results of such experiments yield objective descriptions of the facts about visual acuity, color vision, distance perception, object recognition, and so on.

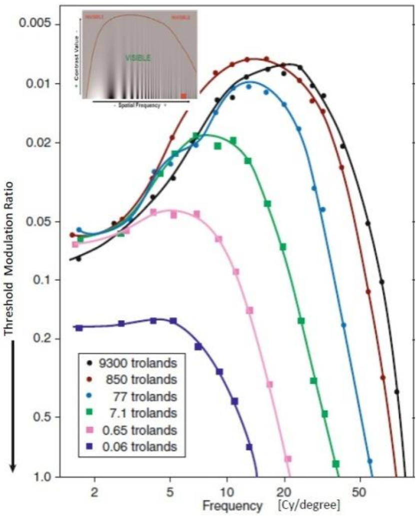

Figure 3. HVS contrast sensitivity function [23] (perceived threshold contrast) fir different retinal illumination values[1]

The selected human visual system - HVS properties describing limiting possibilities are [23-25]:

- Contrast sensitivity as illustrated in Fig. 3,
- Resolution power (Nyquist limit) – 56 cycles/degree,
- Visual acuity limit – 1 arc-minute typical, minimum perceptible limit 0.3 arc-minute,
- Dynamic Range – 10^{-6} - 10^{6} nits (cd/m^2),
- Critical Flicker Frequency – CFF – 60 – 72 Hz.

HVS is adapted to be sensitive in the wide range of illumination levels - starting at less 1 mlux (night, starlight) up to more than 100 klux (direct sun illumination) for natural illumination, and up to 2klux artificial illumination (office environment).

Modeling of human vision has a long development history based on the results of psychometrics results and defined needs for aimed application. The basic principles are based on proper analytical modeling starting from known experimental results. One of the best known models [26, 27] is based on the modeling of the contrast sensitivity function dependence on spatial frequency and level of illumination (see Fig. 3). Further development introduced models that involved HVS motion sensitivity (both eye motion and motion in image), temporal sensitivity and color sensitivity.

HVS-based approach is significant and applies to a large variety of image processing applications. In addition, HVS system properties define optimal conditions for human image perception and interpretation and ultimate display screen properties. However, the human visual system is extremely complex, and many of its properties are not well understood even today. Significant advancements of the current state of the art will require an in-depth understanding of human vision for the design of the radiographic monitors – workstations.

The human visual system can be subdivided into two major components:

- the eyes, which capture light and convert it into signals that can be understood by the nervous system,
- the visual pathways in the brain, along which these signals are transmitted and processed.

Contrast sensitivity is defined as the inverse of the contrast threshold. Contrast sensitivity is closely connected with Weber's Law that has two key consequences:

- The contrast sensitivity is approximately independent of the background luminance.
- Relative changes in luminance are important.

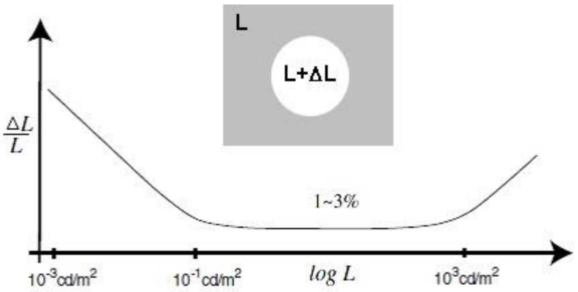

Figure 4. Weber – Fechner Law

As one can see form Fig. 4 [28], this is not valid for very low and very high luminance values:

- At very low luminance, detector noise, and ambient light tend to reduce sensitivity, so the stimulus appears "black".

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[1] *The troland (symbol Td) is a unit of conventional retinal illuminance. It is equal to retinal illuminance produced by a surface whose luminance is one nit* ***[cd/m^2]*** *when the apparent area of the entrance pupil of the eye is 1 mm^2. This quantity is used to scale scene luminance to retinal illuminance according to eye entrance pupil area.*

- At very high luminance, the very bright background tends to saturate detector sensitivity, thereby reducing sensitivity by "blinding" the subject.

We are mostly concerned about low and mid-range of the image luminance values. HVS is optimally adapted to have best contrast sensitivity for image luminance values in the range 10-1 to 103 cd/m2, as illustrated in Fig. 3 and 4.

There is a lot of work to involve attention, adaptation and image content in related HVS models and facilitate new more complete and generalized model developments. In the same time there is need for new systematic psychometrical measurement tailored to support mathematical modeling. This is rapidly developing area requiring new break through to support new image processing needs.

The spatial resolution of the human eye depends on the position of the image inside eye field of view, defined through angular position against eye optical axis, as illustrated in Fig. 5. The practical consequence of the limited HVS resolution is that eye could to resolve two points at distance of about 150 µm in the image plane viewed from mean observation distance of about 50 cm, leading to requirements that display resolution should be at least 170 pixels per inch - PPI for observation distance of 50 cm. One arc minute eye resolution is a key parameter, so for different observation distances resolution in the image plane will be different accordingly.

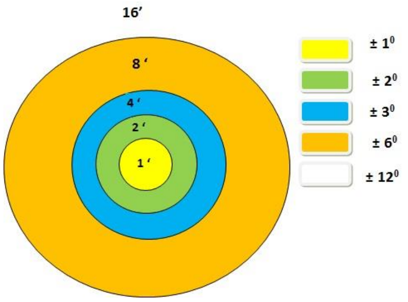


Figure 5. Eye resolution through eye FOV

While the visual system is highly adaptive, it is not equally sensitive to all stimuli. There are a number of inherent limitations with respect to the visibility of stimuli.

- The response of the visual system depends much more on the contrast of patterns than on their absolute light levels (Weber's Law).
- Visual information is processed in different pathways and channels in the visual system depending on its characteristics such as color, spatial and temporal frequency, orientation, phase, direction of motion, etc. These channels play an important role in explaining interactions between stimuli.
- Color perception is based on the different spectral sensitivities of photoreceptors and the decorrelation of their absorption rates into opponent colors.

HVS has complex structure and role in image perception. The basic component is eye, but eye brain connection provides full image understanding and perception. Eye provides detection of visual information as first step, but brain provides interpretation of visual images and cognitive interpretation of visual signals [28]. Because of that image display should be optimized due to perception [29], in addition to its physical properties.

IV. DISPLAY TECHNOLOGY LIMITATIONS

During the second half of 20th century a lot of different display technologies were developed, as illustrated in Fig. 6.

Cathode ray tubes – CRT made a first break through in display mass application and production nowadays is obsolete technology still applied in some old radiography systems. Active matrix liquid crystal – AMLCD technology nowadays dominates on the market due to best achievable performances [30]. Some other technologies have advantages in selected applications, for example OLED (Organic Light Emitted Diodes) technology has better color reproduction but could not to achieve high luminance values.

Other display technologies are still developing showing better characteristics in selected applications, but AMLCD technology provides the solution as radiographic display having comparable and even overrides performances of the film based radiographic systems [31].

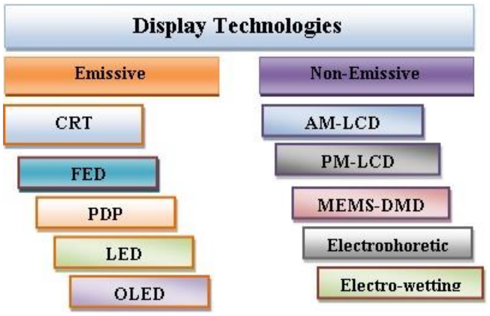


Figure 6. Display technology classification

To provide medical displays having ultimate performances sometimes is possible to apply additional ruggedization techniques (AR - antireflective layer addition) as in high performance military displays [32-34].

Ambient illumination causing image contrast degradation is critical factor for display technology usability evaluation [35].

Handheld display [32], [36] size, resolution, viewing distance, and even brightness are not significant problem for image presentation and viewing. Touch screen interfaces can be designed to leave an image area clear of fingerprints and have low diffusive reflection, but high specular reflections [37] may be the most significant issue causing disruptive glare. This could be mitigated by device position, but user should always take care about illumination environment. Touch screen supported image manipulation commands and portability make their application attractive, but they are not ready to be recommended as diagnostic displays, although they could be successfully used in other applications.

A mobile and hand held devices aimed to display pictures for the user, without clear intent about what type of pictures, could not be considered as a medical diagnostic display even if they are used to present medical images. These devices might display medical images for educational or reference purposes. In addition, if one intends to display medical images for a radiologist for diagnostic purposes that device should be examined and certified as a class II medical device.

V. DISPLAY BASIC PERFORMANCE REQUIREMENTS

Display quality is one of the main factors that influence the quality of medical softcopy images perception and accordingly contributes to diagnostic quality. Current status of display technology and display metrology provide sufficient basis for display parameters definition and evaluation using well defined measurement methods. On the other hand medical diagnostic softcopy digital image standards are suitable to provide additional digital image quality criteria that are connectable with display parameters. Display parameters are assessed using objective measurements (luminance, viewing angle, distortion, uniformity, spatial resolution, switching parameters, chromaticity, etc.). DICOM (Digital Imaging and Communications in Medicine) [38], standard specifies additional requirements for display luminance response characteristic curve providing perceptual linearity and adaptation to HVS contrast sensitivity.

Medical display basic performances review is derived for diagnostic medical displays following key standards [19-22], [38-44] aiming to present the values of the key parameters as illustration.

Screen Size and aspect ratio

Medical diagnostic displays should to provide good visualization of the whole screen from typical viewing distance. It was found that diagonal of the display should be about 80% of viewing distance. At 2/3 m viewing distance corresponding display diagonal is 21” (53 cm).

Radiological displays are usually designed to have aspect ratio 4:5, (5:4) and diagonal size about 21” (53 cm), following radiological film typical size.

Pixel pitch (PP) and resolution

Traditionally resolution of medical monitors has been described by number of pixel in the screen array. The term resolution related to displays has a two different meanings: (a) number of pixels in the display array – display pixel count expressed in megapixels – MP, and (b) display spatial resolution ie. display ability to present two points that could be clearly discerned. Digital display has clearly defined pixels with same shape. Display spatial resolution is measured using pixel pitch (PP) as distance between centers of two neighboring pixels. Due to limited screen size it is common to use term resolution expressed as total number of pixels (often 3 or 5 MP) to have a good sense of display spatial resolution. Following HVS spatial resolution of one minute there is recommendation that pixel pitch should be 0,2 mm (maximum 0,21 mm) [29] to provide image perception without detection of individual pixels – pixilation when display is observed from normal viewing distance of about 20” (50 cm). Of course pixel pitch could be lower than 0,2 mm, but this will not result in better perception of image details. Lower pixel pitch would exceed the acuity of eye.

Nowadays diagnostic displays use several resolutions: (a) 2MP (1200X1600, PP=0,27mm), 3MP (1536X2048, PP=0,212mm), 5MP (2048X2560, PP=0,165 mm), what are sufficient for radiographic displays.

Means, 3MP or 5MP monitors are good enough to provide medical (radiographic) image presentation and perception.

New developments provide higher display resolutions (UHD – ultrahigh resolution - 4k UHD (3840X2160) and 8k UHD (7680X4320) that could be used in the displays for clinical review, depending on the display size. New developments in bio medical imaging systems could find proper display solution using UHD displays for related image presentation.

Brightness (Luminance)

Digital displays present image by generating spatial light distribution as defined in the soft image file. Means, display emit light having specific spatially distributed luminance (brightness). The level of image luminance is very important for image perception. The light box used for radiological film observation luminance is leading value for medical display luminance definition (light box luminance is about 2000cd/m^2). Another important factor is determined with HVS properties – optimal image luminance range for image perception. To define display luminance there are several quantities of importance:

Maximum luminance – L_{max} - .The luminance produced when the maximum value of input signals is input.

Minimum luminance – L_{min} –The luminance produced when the minimum value of input signals is input.

Ambient Luminance – L_{amb} - The luminance observed on the surface of display system when the display system is switched off, and represents the contribution of the ambient illumination.

Luminance ratio - The luminance ratio is expressed in (L_{max} + L_{amb}) / (L_{min} + L_{amb}). In the guidelines, in order to make the measurement values reproducible, L_{amb} = 0 in principle. In practice, therefore, the luminance ratio is used as L_{max} / L_{min}.

Consumer grade displays typically offer a maximum luminance of 250 – 300 cd/m^2, and minimum luminance is not defined - ND. Medical diagnostic displays should to provide luminance level higher than 500 cd/m^2 and luminance ratio higher than at least 300 or even 500.

State-of-the-art medical displays achieve luminance levels of more than 1000 cd/m^2, much closer to conventional film. Minimum luminance is very important and should be less than 1 cd/m2. Minimum luminance is often referred as “level of black” which is important for image contrast detection. To minimize display ambient luminance display surface should be covered by antireflective – AR coating. To be considered as negligible L_{amb} should be lower than ¼ L_{min}.

According to DICOM 3.14 [20], a larger luminance range results in a broader spectrum of grayscales that can be discerned by the human eye as defined by sensitivity increment known as JND - Just Noticeable Differences.

The additional three critical parameters related to display luminance are usually defined:

Contrast (contrast ratio)

Luminance is not the only important parameter for diagnostic reading. For many applications, contrast ratio is even more important than luminance. Higher contrast ratio provides lower luminance level for black patches. Medical displays offer a contrast (up to 1000:1) that is substantially better than most consumer displays, which have on average a contrast ratio of only 300:1.

Uniformity

All LCD displays suffer from luminance non-uniformity due to imperfection of the display backlight design. This means that images will appear slightly differently in the corner of the display than in the center. Using LED based backlights (both waveguide based or direct backlight) it is possible to achieve high level of uniformity value in the medical diagnostic displays. This luminance non-uniformity measured using 5 point scheme [16] can be as much as 25-30 % for commercial displays, but for diagnostic image display non-uniformity value of 10% is recommended.

Grayscale display function (GSDF) and grayscale range

A function that describes the mapping of the display video digital driving level (DDL) to defined display luminance (gray level) is called *display characteristic curve*. The characteristic curve depends on operating parameters of the display system.

It has been established that the human visual system responds nonlinearly to input luminance, and that fact is partially corrected through display characteristic curve (usually described as γ function). In the case of medical diagnostic displays a consistent reproduction of gray levels on different displays is very important. Because of that additional display calibration is required and defined through grayscale calibration using standardized function providing that each equal step in image signal should to produce a perceptually equal luminance change.

The *Grayscale Standard Display Function* (GSDF).is standardized function derived from Barten's HVS sensitivity model [26], [27] and defined in DICOM (Digital Imaging and Communications in Medicine) standard [20], [39].

The Barten model defining the Greyscale Standard Display Function (GSDF) is based on human Contrast Sensitivity using the concept of Just Noticeable Differences (JND) to define input image related value.

A Display Function that adjusts the brightness such that equal changes in pixel values will result in the same level of perceptibility at all driving levels of signals supplied to the monitor is "perceptually linearized" [45]. Thus the GSDF incorporates the notion of perceptual linearization.

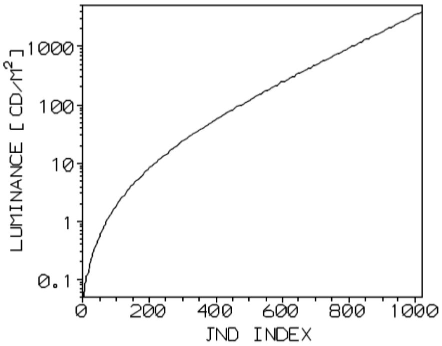


Figure 7. The DICOM calibration curve based on Barten equation for transformation of JND index to display Luminance [39]

Just-Noticeable Difference (JND) is the luminance difference of a given target under given viewing conditions that the average human observer can just perceive. The luminance range seen by an average observer is divided into a fixed number of just distinguishable luminance values. The model determines the maximum number of shades of grey that can be visualised on a given display.

The *JND index* represents changes in input relative to changes of luminance levels in JND steps on the GSDF.

The typical shape of the DIKOM GSDF [39] is illustrated in Fig. 7. GSDF function is incorporated in display controls using look-up tables (LUT) determined through calibration process. It is recommended that calibration of the clinical medical displays should be done regularly, at least once a year.

The number of available shades of gray on most consumer displays is limited to 256 (8 bit). Medical displays should have a much wider grayscale range, enabling them to render every grayscale as defined by DICOM. The wide grayscale displays, for instance, should to provide up to 4096 shades of gray (12 bit). The most of currently used medical diagnostic displays have 1024 (10 bits) gray shades. Such an extensive range is necessary to comply with the guidelines for gray scale calibration for medical diagnostic displays [20, 39]. Displays with a grayscale resolution of 8 bit will fail to meet this requirement for medical diagnostic displays but could be suitable for other applications.

The application of the GDSF calibration is widely adopted but still has some limitations. It is based on HVS contrast sensitivity measurements using specific sinusoidal grating which is not always related to details contained in medical images. Also, Barten's model derived from measurements is based on mean luminance in pattern assuming that observer's eye is adapted to that luminance level. When viewing a fixed scene an observer's eye is adapted to the average luminance falling to retina that is not equal to the observed details, so contrast sensitivity could be different.

Despite its limitation calibration to the DICOM GDSF is widely accepted and provides more consistent medical radiologic images presentation. It is possible that in the future scientist will find function that better represents HVS contrast sensitivity for medical images, but the concept of display calibration will be applied.

Color properties and color gamut

Originally medical diagnostic displays used for radiographic image presentation are designed as black and white –B/W displays [41, 42] without any color. Nowadays, it is often case that color display are used for B/W image presentation with same success [43]. Some application in mammography displays [44] found benefits of introducing color (pseudo-coloring) in displayed images. Also other medical imaging applications use a color in image presentation.

There are efforts to define standardized color gamut and color calibrations for medical grade displays [46], but this is still not developed. The key problem is because it is hard to keep GSDF calibration and color gamut calibration in the same time. In the case of diagnostic displays GSDF calibration [47, 48] is considered as more important and keeping color shade constancy in all displays is less important. The temporally solution for color properties solution is to define color of white (WP), and use some standardized color gamut for color properties definition. The shape of selected color gamut as defined by International Color Commission (ICC) is presented in Fig. 8. Means the combination of ICC and DICOM based calibration procedures is considered as good solution for now**.**

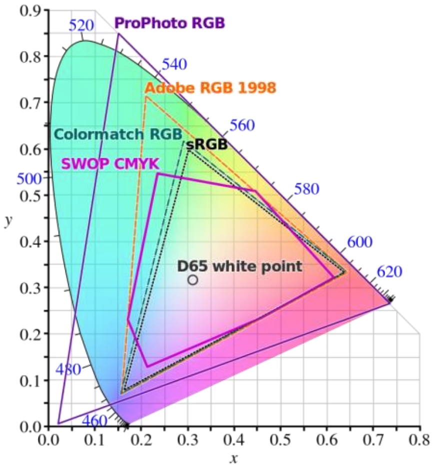


Figure 8. Examples of the standardized color gamut shapes for information displays (as per Wikipedia: Color Space)

The display color calibration keeps color shade presentation constant through calibrated displays. In the case of the pseudo-color images the constancy of color shade is not of key importance for diagnostic, but in some other applications of digital displays it could be. It is expected that proper solutions for GSDF and color calibration could be defined to fulfil current and future need.

TABLE I. MEDICAL DIAGNOSTIC DISPLAY PROPERTIES REVIEW

Display property	***Medical Diagnostic Displays***	***General Information Displays***
Diagonal Size	21” 952 (52 cm)	various
Resolution	3MP (PP=0,21mm) 5MP (PP=0,167mm)	Various, From VGA to 4k UHD (3840X2160) and 8k UHD (7680X4320)
Maximum Luminance	>300(500) cd/m^2	Up to 250 cd/m^2
Minimum Luminance	<1 cd/m^2	N/D
Ambient Luminance	<1/4 L_{min}	N/D
Luminance Ratio	>300(500)	N/D
Contrast	>500 (1000)	Up to 300
Non Uniformity	<10%	About 25%
Display characteristic curve	GSDF calibrated	N/D
Number of gray shades	>10(12) bit 1024 (4096	8 bit – 256
Color Gamut Calibration, Consistency	N/D	NTSC, sRGB, AdobeRGB,
Special display design features	AR coating Maximal display luminance control	Touch panel compatibility

The review of the selected medical diagnostic display properties compared with consumer information display properties is presented in TABLE I. We are concentrated on properties of digital medical diagnostic displays because their properties are the most demanding and their properties are regulated by standards. Other medical imaging display properties are more close to consumer information display properties, but depending on application some other specific requirements could be defined and would be standardized in the future.

VI. MEDICAL DISPLAY QUALITY ASSESMENT

Medical image diagnostic quality achievement is complex task depending mostly on technical capabilities of imaging system to collect digital images containing recognizable details (size and contrast) that are already recognized in the knowledge basis of the concerned pathological conditions suitable for examination with expert.

Medical digital images application is nowadays widely spread. Some of imaging files are complex and have high size, need complex processing and image manipulations so they are also regulated by DICOM [38] and PACS (Picture Archiving and Communication System) [39, 49] rules.

Medical display image quality is incorporated in the diagnostic quality as a key step. Diagnostic quality is very complex and is derived from diagnostic efficacy that has several levels [50], as presented in TABLE II.

TABLE II. HERARCHY OF DIAGNOSTIC LEVEL EFFICACY [50]

Levels of diagnostic efficacy	Definition	Commonly measured parameters
Technical efficacy	System or test fidelity. How accurately and precisely it measures what is to be measured.	Physical parameters
Diagnostic accuracy efficacy	How well or accurately a system or test predicts presence/absence or extent/magnitude of a disease or health condition.	Sensitivity, specificity, ROC area under the curve
Diagnostic thinking efficacy	Impact of diagnostic test results on clinician’s estimate of the probability that a patient suffers from a disease or health condition.	Changes in diagnosis, before and after a diagnostic test
Therapeutic efficacy	Whether or how much the system or test changes patient’s course of treatment/care.	Changes in treatment
Patient outcome efficacy	Degree to which patient’s health/condition improves.	Survival rates, quality of life
Societal efficacy	Impact of the system/test on society as a whole.	Cost-benefit analyses,

Diagnostic Quality measurement is extremely complex because pathological condition is what determines the information which must be retained in any given medical data but not sufficiently contrasted with surrounding tissue or small in size in comparison with resolution of data collection system.

Diagnostic quality is therefore highly dependent on the properties of the whole imaging chain and requires very specific and diversified assessment methods.

Digital display image quality is involved only in the first two levels as defined for medical efficacy. Other levels of diagnostic quality could be determined through systematic long term studies using statistical method for diagnostic data impact.

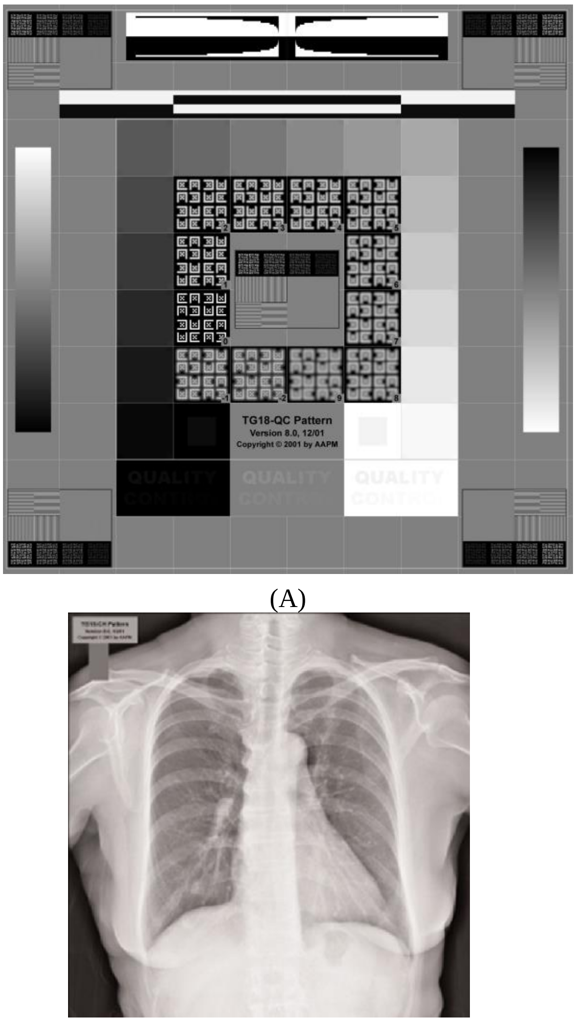
Numerous studies were conducted to develop standard methods that evaluate diagnostic accuracy in medical images in order to improve radiologists’ performance and reduce their interpretation variability. The first level of diagnostic accuracy assessment could be realized using objective measurement methods and comparison with predefined standards. The second level of diagnostic accuracy evaluation usually use

Receiver Operating Characteristic (**ROC**) techniques [51] that measure diagnostic accuracy using comparative subjective assessment for defined use case tracking sensitivity, differences through statistical analysis where the area under ROC curve is key judging parameter.

Objective assessment metrics often use just noticeable difference (**JND**) models [52] that simulate human visual system perception and model observers as a tool that predicts image quality performances. Radiological display quality assessment is well standardized in the AAPM TG-18 [19] standard. The complete measurement methods together with set of test images (see some examples in the Fig. 9), are defined in this standard. The similar standard is developed by other medical physics committees [53].

The TG-18 standard is in use and improved more than 20 years and its application leads to improvements in radiological display quality [54, 55].

Using standardized methodology a lot of research is done to determine influence of the luminance settings environmental illumination on diagnostic accuracy [56, 58].



(A)

(B)

Figure 9. Medical display Qualitu assessment test patterns [19]: (A) TG-18 multipurpose test pattern; (B) Chest test image

The general block diagram (Image Quality Circle) [54] of the medical display assessment process is illustrated in Fig. 8. In the case of diagnostic digital medical display quality assessment is performed using objective measurement methods defined in standards [19-22]. The general information display measurement standards are applicable [16], too. The most challenging task is to find correlation between perception and system physical – measurable parameters. All standardization and assessment method developments are aimed to achieve digital medical displays optimization for best image perception in clinical application environment [29, 59].

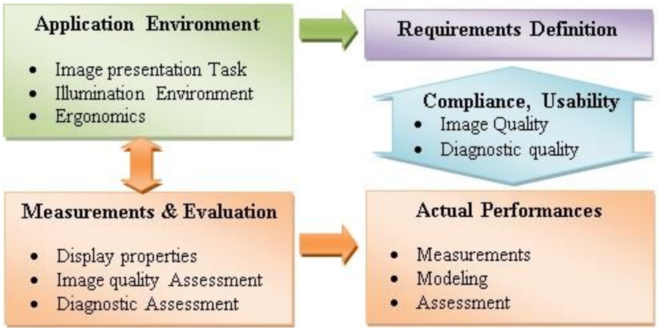


Figure 10. Medical display diagnostic quality assessment circle

The most of assessment methods, mentioned, are intended for radiological diagnostic displays, but they are applicable for other medical displays.

VII. CONCLUSIONS

Monitor displays play an important role in modern radiology practice. Practicing radiologists need to be familiar with the various performance parameters of medical-grade displays, since the right choice of equipment can have a great impact on the accuracy, efficiency, and speed in the radiology department. The basic technical knowledge necessary when making purchasing decisions together with selected data related to the perception of the medical radiographic images that could be useful to the digital medical display designer, are presented in condensed form in the article

Image quality is important in medical imaging because images are viewed by physicians for diagnosis, for planning of therapy, for application of therapy, and for assessment of therapy. Since the diagnostic task is often one of detecting a lesion, there is a long history in medical imaging of quantitatively measuring image quality as the capability to detect a target defect. The basic medical display assessment and calibration methods are discussed. Researchers use experimental methods such as the receiver operator characteristic – ROC and forced choice, accompanied with theoretical analyses using a variety of models of human detection. Most often, this has been done in projection x-ray and nuclear medicine imaging where ionizing radiation must be limited and quantum noise is often a factor.

Several important concepts of vision were presented. The major points can be summarized as follows:

- The human visual system is extremely complex.
- While the visual system is highly adaptive, it is not equally sensitive to all stimuli. There are a number of inherent limitations with respect to the visibility of stimuli.
- The response of the visual system depends much more on the contrast of patterns than on their absolute light levels.
- Visual information is processed in different pathways and channels in the visual system depending on its

characteristics such as color, spatial and temporal frequency, orientation, phase, direction of motion, etc.

- Color perception is based on the different spectral sensitivities of photoreceptors and the decorrelation of their absorption rates into opponent colors.

Display characteristics should not to degrade human visual system perception that is used as key criteria in the design of vision models and quality metrics.

It is important to understand photometric properties of the physical world (objective characterization of visual perception illumination environment) and displayed image visual content influence to extraction of the diagnostic data.

Understanding design of the whole imaging system is important in diagnostic quality assessment.

Medical digital imaging applications are diversified and require o lot of digital image processing through imaging chain [60]. A lot of job is done but there are new challenges same in digital image processing and in application of display technology. This review is concentrated on display technology role but it is impossible to avoid interconnections in the whole imaging chain. More research efforts are expected that will lead to better diagnostic efficacy and quality contributing the benefits to health protection.

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REFERENCES

[1] Joseph D. Bronzino, Donald R. Peterson (Editors), THE BIOMEDICAL ENGINEERING HANDBOOK (4. edition) - Biomedical, Signals, Imaging and Informatics, CRC Press, Taylor & Francis Group, Boca Raton, 2015

[2] Isaak F. Bankman (Editor), Handbook of Medical Image Processing and Analysis, Academic Press is an imprint of Elsevier Inc, London, 2009

[3] Jacob Beutel, Harold L. Kundel, RichardL. Van Metter (Editors), Handbook of MedicalImaging: Volume 1. Physics and Psychophysics, SPIE Press, Bellingham, Washington, USA, 2000

[4] Milan Sonka, J. Michael Fitzpatrick (Editors), Handbook of MedicalImaging: Volume 2. Physics and Psychophysics, SPIE Press, Bellingham, Washington, USA, 2009

[5] Yongmin Kim, Steven C. Horii (Editors), Handbook of Medical Imaging: Volume 3. Display and PACS, SPIE Press, Bellingham, Washington, USA, 2000

[6] Janglin Chen, Wayne Cranton, Mark Fihn (Eds.), Handbook of Visual Display Technology, Springer-Verlag Berlin Heidelberg 2012

[7] Ralf R. Hainich, Oliver Bimber, Displays: Fundamentals and Applications, CRC press, Teylor & Francis Group, Boca Raton, 2017

[8] Robert H. Chen, Liquid Crystel Displays: Fundamental Physics and Technology, John Wiley & SonsInc., Hoboken,New Jersey, USA, 2011

[9] Deng-Ke Yang, Shin-Tson Wu, Fundamentals of Liquid Crystal Devices, John Wiley & Sons Inc., Chichester, England, 2006

[10] Takatoshi Tsujimura, OLED Display Fundamentals and Applications, John Wiley & Sons Inc., Hoboken,New Jersey, USA, 2017

[11] S.M. Kelly, FlatPanel Displays: Advanced Organic Materials, Monograph ,The Royal Society of Chemistry, Cambridge, UK, 2000

[12] Theodore Soller, Merle A. Starr, George E Valley Jr., (Editors), Cathode Ray Tube Displays, McGraw-Hill Book Company, Inc. New York, USA, 19486

[13] Adrijanus J.S.M de Vann, "Competing display Technologies for the Best Image Performances", Journal of the SID,15/9, pp.657-666, 2007

[14] M.F. Cowlishaw, "Fundamental Requirements for Picture Presentation", Proceedings of the SID, Vol. 26/2 , pp.101-106, 1985

[15] Michael J. Flynn, "Image Presentation: Implications of Processing and Display", A NIOSH Scientific Workshop, March 12-13, 2008, Washington, 2008

[16] Society of Information Displays, IDMS v.1.03: Information Display Measurement standard, June 01, 2012

[17] - Display Quality Assurance, The Report of AAPM Task Group 270, January 2019

[18] --, ASSESSMENT OF DISPLAY PERFORMANCEFOR MEDICAL IMAGING SYSTEMS, AAPM On-line Report No. 03, American Association of Physicist in Medicine, Task Group 18, Imaging Informatics Subcommittee 2005

[19] -- PS3.14: DICOM PS3.14 2019e - Grayscale Standard Display Function, DICOM, 2019

[20] Kocić, J., Popadić, I. Livada, B. "Image Quality Parameters: A Short Review and Applicability Analysis", Proc. of 7th International Scientific Conference on Defensive Technologies (OTEH 2016, Belgrade, October 6-7, 2016, pp: 391-397, 2016

[21] E. Samei et al., "Assessment of display performance for medical imaging systems: Executive summary of AAPM TG18 report," Med. Phys. 32,pp:1205–1225, 2005

[22] Bruno Ribeiro de Mesquita, C. Ferreira, Divanizia do Nascimento Souza, "Quality Control of Display Devices for Medical Radiodiagnosis Employing the Standard TG18, GSDF and JND", The Open Medical Devices Journal, Volume 6, pp: 21-32, 2018

[23] Branko Livada, "Sun and Displays, Old stories and new chalenges", Proccedings IcETRAN 2019, Srebrno Jezero, Serbia, 3-6 juna 2019

[24] David G. Curry, Gary Martinsen, and Darrel G. Hopper, "Capability of the human visual system", Cockpit Displays X, Darrel Hopper, Editor, Proceedings of SPIE, Vol. 5080 , 2003

[25] Kara Rogers (Editor), The eye: the physiology of human perception, Britannica Educational Publishing (in association with Rosen Educational Services, LLC, New York, 2011

[26] Barten, P.G.J., "Physical Model For The Contrast Sensitivity Of The Human Eye", Proc. SPIE 1666, pp57-72, 1992

[27] Peter G.J Barten, Contrast sensitivity of the human eye and its effects on image quality, Knegsel: HV Press, 1999

[28] William R. Hendee, Peter N.T. Wells(Editors), The Perception of visual information - 2nd ed., Springer-Verlag New York, Ine., 1997

[29] Mark F. McEntee, Rachel J. Toomey; "Display Optimization from a Perception Perspective", Ch 30. in The Handbook of Medical Image Perception and Techniques edited by Ehsan Samei, pp 452-469, Cambridge University Press, London, 2018

[30] William Pavlicek, James M. Owen, and Mary Beth Peter, "Active Matrix Liquid Crystal Displays for Clinical Imaging: Comparison With Cathode Ray Tube Displays", Journal of Digital Imaging, Vo113, No 2, Suppl 1 (May), 2000: pp 155-161

[31] Hai-Wei Chen, Jiun-Haw Lee, Bo-Yen Lin, Stanley Chen and Shin-Tson Wu, "Liquid crystal display and organic light-emitting diode display: present status and future perspectives", *Light: Science & Applications* No 7, 2018

[32] - Considerations for the Use of Handheld Image Viewers, The Report of AAPM Task Group 260, 2011

[33] Branko Livada, "Avionic Displays", Scientific Technical Review, Vol.62,No.3-4,pp.70-79, 2012

[34] Branko Livada, Radomir Jankovic, Nikolic, "AFV Vetronics: Displays Design Criteria", Strojniški vestnik - Journal of Mechanical Engineering (JME), vol.58, No6, 376-385, 2012

[35] Haiwei Chen, Guanjun Tan, Shin-Tson Wu, "Ambient contrast ratio of LCDs and OLED displays", Optix Express, Vol. 25, No. 26, pp 33643-33656, 2017

[36] Yamazaki A, Liu P, Cheng W-C, Badano A., "Image Quality Characteristics of Handheld Display Devices for Medical Imaging",. PLoS ONE 8(11):e79243, 2013

[37] John W. Stetson, „Analog Resistive Touch Panels and Sunlight Readability", Information Display 12/06, pp.26-30, 2006

[38] Oleg S. Pianykh, Digital Imaging and Communications in Medicine (DICOM): A Practical Introduction and Survival Guide, Springer-Verlag Berlin Heidelberg 2012

[39] Aldo Badano, "AAPM/RSNA Tutorial on Equipment Selection: PACS Equipment Overview: Display Systems", RadioGraphics, 24, pp:879–889, 2004

[40] Michael J Flynn, Jerzy Kanicki, Aldo Badano, William R. Eyler, "High-Fidelity Electronic Display of Digital Radiographs", RadioGraphics, 19, pp. 1653-16669, 1999

[41] George C. Kagadis, Alisa Walz-Flannigan, Elizabeth A. Krupinski, Paul G. Nagy, Konstantinos Katsanos, Athanasios Diamantopoulos, Steve G. Langer, "Medical Imaging Displays and Their Use in Image Interpretation", RadioGraphics 33; pp:275–290, 2013

[42] – Worldwide Implementation of Digital Imaging in Radiology – A Resource Guide, *IAEA Human Health Series No.28,* International Atomic Energy Agency, Vienna, 2015

[43] Hakan Geijer, Mats Geijer, Lillemor Forsberg, Susanne Kheddache, Patrik Sund, "Comparison of Color LCD and Medical-grade Monochrome LCD Displays in Diagnostic Radiology", Journal of Digital Imaging, Vol 20, No 2 pp 114-121, 2007:

[44] Eliot Siegel, Elizabeth Krupinski, Ehsan Same, Michael Flynn, Katherine Andriole, Bradley Erickson, Jerry Thomas, Aldo Badano, J. Anthony Seibert, Etta D. Pisano, "Digital Mammography Image Quality: Image Display", Journal of the American College of Radiology Vol. 3 No.8, pp: 617-627 , 2006

[45] Kenneth A. Fetterly, Hartwig R. Blume, Michael J. Flynn, and Ehsan Samei, "Introduction to Grayscale Calibration and Related Aspects of MedicalImaging Grade Liquid Crystal Displays", Journal of Digital Imaging, Vol 21, No 2, pp: 193-207, 2008

[46] Aldo Badano et all, "Technical Note: Gray tracking in medical color displays—A report of Task Group 196", Med. Phys. 43 (7), pp: 4017-4022,July 2016

[47] Antonio J. Salazar, Diego A. Aguirre, Juliana Ocampo, Juan C. Camacho, Xavier A. Díaz, "DICOM Gray-Scale Standard Display Function: Clinical Diagnostic Accuracy of Chest Radiography in Medical-Grade Gray-Scale and Consumer-Grade Color Displays", AJR Am J Roentgenol.;202(6), pp. 1272-1280, 2014

[48] Elizabeth A. Krupinski, Mark B. Williams, Katherine Andriole, ,Keith J. Strauss, Kimberly Applegate, Margaret Wyattf,Sandra Bjork, J. Anthony Seibert, "Digital Radiography Image Quality: Image Processing and Display", J Am Coll Radio;4, pp:389-400, 2007

[49] H.K. Huang, PACS and imaging informatics : basic principles and applications. – 2nd ed. Rev, John Wiley & Sons, Inc., Hoboken, New Jersey, 2010

[50] Dennis G. Fryback and John R. Thornbury, "The Efficacy of Diagnostic Imaging", Medical Decision Making, Vol 11, No2, pp. 88-94, 1991

[51] Karimollah Hajian-Tilaki, „Receiver Operating Characteristic (ROC) Curve Analysis for Medical Diagnostic Test Evaluation", Caspian J Intern Med; 4(2), pp. 627-635, 2013

[52] Jeffrey Lubin (Editor), Sarnof JND Vision Model - Algorithm Description, Sarnof Contribution to IEEE standards subcomittee, 1997

[53] --- Quality Assurance (QA) Guidelines for Medical Imaging Display Systems, English translation of Japanese JESRA X-0093*A-2010. Japan Industries Association of Radiological Systems, 2010

[54] Elizabeth A. Krupinski, Yulei Jiang, "Anniversary Paper: Evaluation of medical imaging systems", Med. Phys. 35 (2), pp.645-659, 2008

[55] Cédric Marchessoux, Tom Kimpe, and Tom Bert, "A Virtual Image Chain for Perceived and Clinical Image Quality of Medical Display", Journal of Display Technology, Vol..4, No. 4, pp.356-368, 2008

[56]] Magnus Båth, Patrik Sund, Linda Ungsten, Lars Gunnar Månsson, "Calibration of diagnostic monitors: Theoretical determination of optimal luminance settings", Journal of the SID 14/10, 2006

[57] Alberto Laffranchi, Calogero Cicero, Manuela Lualdi, Chiara M. Ciniselli, Giuseppina Calareso, Stefano Canestrini, Francesca G. Greco, Enrico Alberioli, Claudia Cavatorta, Alessandro Guarise, Emanuele Pignoli, Maddalena Plebani, Davide Scaramuzza, Claudio Siciliano, Paolo Verderio, Alfonso Marchianň, "Different pixel pitch and maximum luminance of medical grade displays may result in different evaluations of digital radiography images", La radiologia medica 123:586–592, 2018

[58] Kate Devlin, Alan Chalmer, Erik Reinhard, „Visual Calibration and Correction for Ambient Illumination", ACM Transactions on Applied Perception, Vol. 3, No. 4, pp. 429–452. 2006

[59] Ehsan Samei, Alan Rowberg, Ellie Avraham, Craig Cornelius, "Toward Clinically Relevant Standardization of Image Quality", Journal of Digital Imaging, Vol 17, No 4, pp 271-278, 2004

[60] Fouzia Altaf ; Syed M. S. Islam ; Naveed Akhtar ; Naeem Khalid Janjua: „Going Deep in Medical Image Analysis: Concepts, Methods, Challenges, and Future Directions", IEEE Access, Vol. 7 **:** 16, pp. 99540– 99572, 2019

[61] Branko Livada, Digital Medical Imaging Displays Specification: Understanding Technology Helps to Achieve High Quality in Image Interpretation, XIX International Symposium INFOTEH-2020, Jahorina, 18 - 20. mart 2020, Jahorina, RS, BiH, 2020

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