Digital Medical Imaging Displays Specification Understanding Technology Helps to Achieve High Quality in Image Interpretation

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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, dispalys, 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 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.

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 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.

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 source radiation 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 [17].

Evaluation methodologies cover a broad range, 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 [18] – [22].

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. That 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 Figure 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.

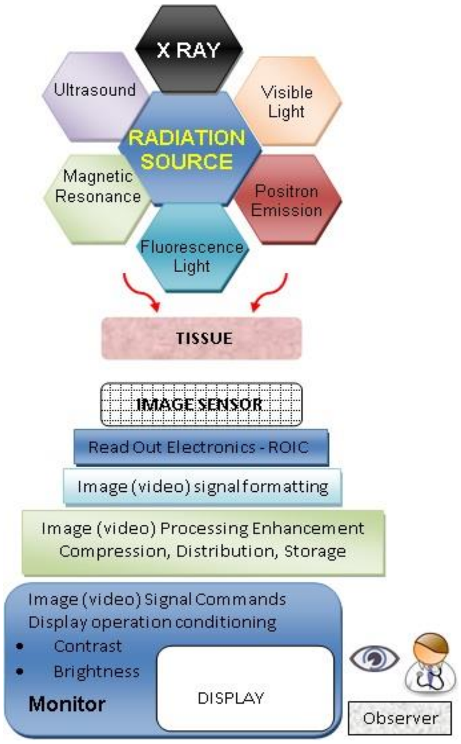

Figure 1. Medical Digital Imaging Chain

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.

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

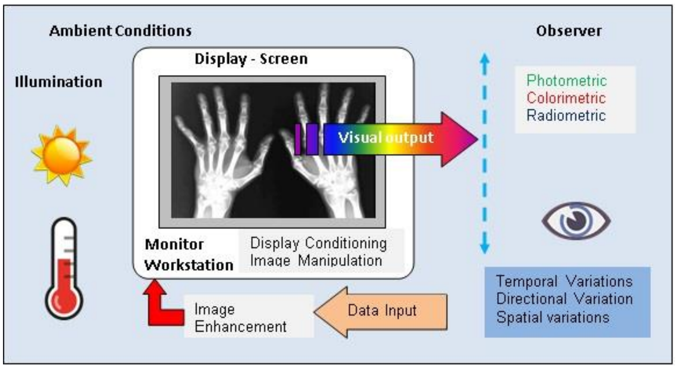

Figure 2. Factors influencing perception of Display visual stimulus

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,

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/m^2 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 about OD = 3, means that film could to provide contrast of about 1000.

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

- diagnostic images (the most demanding)
- clinical review - informative images and video presenting
- sharing images as addition to other data and information.

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.

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

- Contrast sensitivity as illustrated in Figure 3,
- Resolution power (Nyquist limit) – 56 cycles/degree,
- Visual acuity limit – 1 arc-minute, 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).

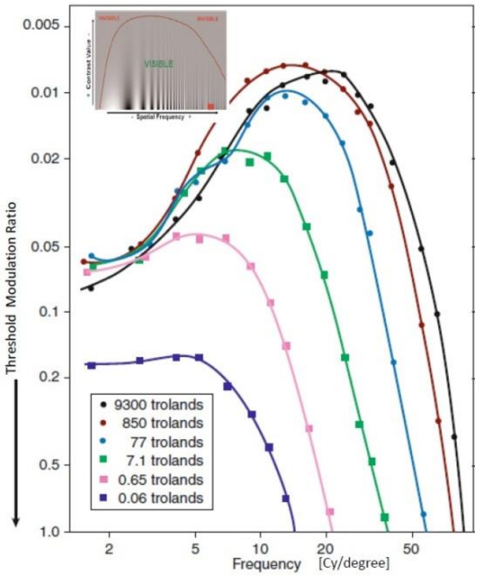

Figure 3. HVS contrast sensitivity function (perceived threshold contrast) fir different retinal illumination values[1]

[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.*

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 Figure 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.

As one can see form Figure 4, 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".
- At very high luminance, the very bright background tends to saturate detector sensitivity, thereby reducing sensitivity by "blinding" the subject.

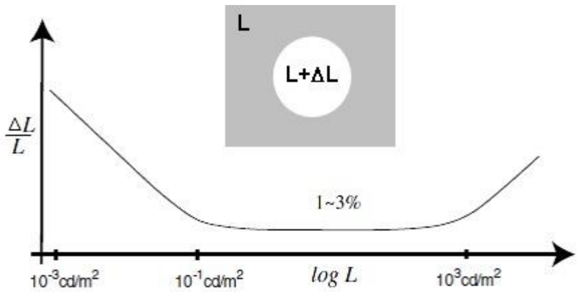

Figure 4. Weber – Fechner Law

We are mostly concerned about low and mid-range of the image luminance values. The Figures 3 and 4 shows that HVS is optimally adapted to have best contrast sensitivity for image luminance values in the range 10^{-1} to 10^{3} cd/m^2.

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 Figure 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.

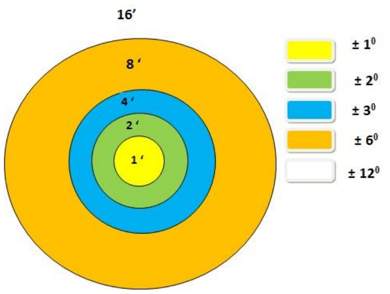

Figure 5. Eye resolution through eye FOV

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.

IV. DISPLAY TECHNOLOGY LIMITATIONS

During the second half of 20th century a lot of different display technologies were developed, as illustrated in Figure 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. Some other technologies has advantages in selected applications, for example OLED - Organic Light 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 [28].

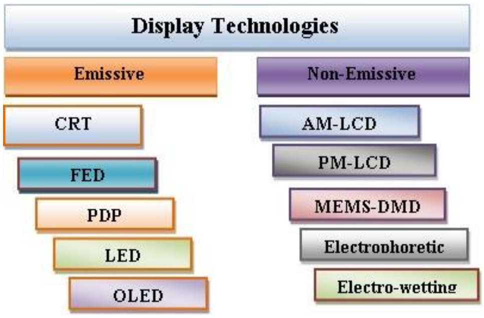

Figure 6. Display technology classification

A mobile and hand held devices intended to display pictures for the user, without clear intent about what type of pictures, could not be considered as a medical display even if they are used to present medical images [29]. These devices might display images for educational or reference purposes. In addition, if one intended to display medical images for a radiologist to diagnose that device should be examined and certified as a class II medical device.

To provide medical displays having ultimate performances sometimes is possible to apply additional ruggedization techniques as in high performance military displays [30-31].

Ambient illumination caused image contrast degradation is critical factor for display technology usability evaluation [32]. Because of that application of the touch screen is practically impossible in diagnostic displays.

V. DISPLAY BASIC PERFORMANCE REQUIREMENTS

Medical display basic performances review is derived for diagnostic medical displays following key standards [19-22], [33-38] aiming to present the values of the key parameters as illustration.

Screen Size and aspect ratio

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

Pixel pitch (PP) and resolution

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.

New developments provide higher resolutions (UHD – ultrahigh resolution - 4k UHD (3840X2160) and 8k UHD (7680X4320)), that could be used in the displays for clinical review.

Brightness (Luminance)

Consumer grade displays typically offer a maximum luminance of 250 – 300 cd/m^2.

State-of-the-art medical displays by contrast achieve luminance levels of more than 1000 cd/m^2, much closer to conventional film. 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 Just Noticeable Differences. The three critical values 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. This means that images will appear slightly differently in the corner of the display than in the center. 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

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). 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.

Gray scale calibration is necessary to provide optimal image presentation and similar to display gamma settings but using look up table derived for Barten's HVS sensitivity model [39].

Color Gamut

There are efforts to define color gamut for medical grade displays [40], but this is still not developed.

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 display image quality is incorporated in the diagnostic quality.

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. Evaluation methodologies cover a broad range, from subjective assessment including the widely used Receiver Operating Characteristic (**ROC**) techniques that measure diagnostic accuracy to objective assessment including metrics such as just noticeable difference (**JND**) models that simulate human visual system perception and model observers that perform classification.

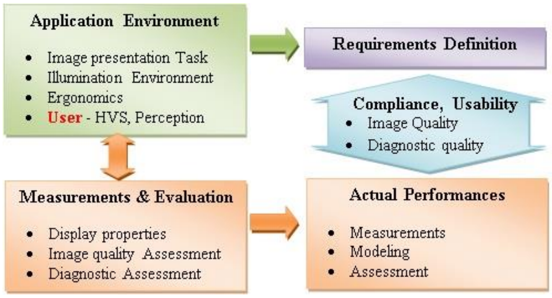

Figure 7. Medical display diagnostic quality assessment

The general block diagram of the medical display assessment process is illustrated in Figure 7. In the case of diagnostic digital medical display quality assessment is performed using measurement methods defined in standards [19-22].The general information display measurement standards are applicable [16], too.

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. A certain amount of technical knowledge is useful when making purchasing decisions since the right choice of equipment can have a great impact on the accuracy, efficiency, and speed in the radiology department.

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. Researchers use experimental methods such as the receiver operator characteristic and forced choice, and 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 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.

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