Comparison of Medical Image Quality between Light-box and Computer Monitor

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Abstract

To investigate the quality of the images displayed on light-boxes and computer monitors, the objective quality measures for image based on a model of the human visual system (HVS) have been studied. In the present study, a modified quality measure for image based on HVS model including luminance factor was developed. Simulated chest lesion patterns were used to demonstrate the influence of luminance on the quality of the image displayed on the computer monitor. The contrasts that resulted in a probability of 0.65 were 0.0225 for 1500 cd/m^2 and 0.03 for 90 cd/m^2 for a nodule with diameter of 0.4 mm. With contrast 0.0225, as the diameter of the nodule increased from 0.4 mm to 2.0 mm, the main component of the frequency response shifted from band 5 to band 3. For pneumothorax pattern, as the detection area becomes smaller, the main component moves from lower band to higher band. We concluded that the luminance difference between light-box and computer monitor contributed to the degraded image quality on computer monitor. Image objects contains high frequency component has lower detectability on computer monitor than on light-box.

Keywords: Local contrast, Luminance, HVS model, Image quality, Computer monitor, Light-box

Introduction

In the computerized hospital environment, a radiologist retrieves medical information such as patient records or computed radiographic images (digital format) from a central database and then studies the information on a computer monitor. Although it is convenient to use computer monitor as a primary display device, research has indicated that degradation of diagnostic accuracy occurs when medical images are displayed on a monitor [1,2]. These studies also indicated that the spatial resolution and the background luminance of the display device might be the factors degrading the performance of the radiologist. The influence of spatial resolution on diagnostic accuracy has been investigated [3,4]; the researchers suggested that 2048-line digital format is an acceptable alternative to the light-box. That is to say, in spatial resolution, most modern 14×17-inch portrait monitors are acceptable display devices for chest radiographic images. As for display luminance, studies [5,6] indicated that high background luminance of the light-box contributed to better detection of small low-contrast objects in mammographic images. The maximum luminance of regular light-boxes and computer monitors are 3000 cd/m2 and 180 cd/m2, respectively. Therefore, it is also possible that the luminance difference between light-box and computer monitor affects the diagnostic accuracy of medical image displayed on computer monitor.

Although subjective tests such as receiver observing characteristics (ROC) have been used to investigate the effect of display luminance on diagnostic accuracy, it is time-consuming and requires many radiologists to participate in the experiment. It is also difficult for the methods to provide quantitative description of the influence of luminance factor. To solve this problem, objective quality measures based on a human visual system (HVS) model have been proposed [6-9]. While these techniques perform well for digital images displayed on monitors with fixed luminance, they have not been used for describing the image quality differences between light-box and computer monitor. In this study, we used the probabilities of detection under different luminance levels to quantitatively compare the image quality between computer monitor and light-box. The probability of detection is a function of display luminance. Two images displayed on computer monitor and light-box are visually equivalent if the probabilities of detection are the same. Simulated lung lesion patterns were used to investigate the influence of display luminance on image quality.

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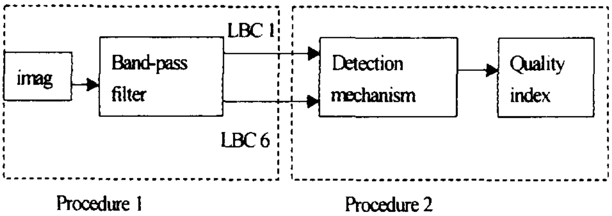

Figure 1. Block diagram of image quality assessment method. LBC 1 and LBC 6 represent the local band-limited contrasts at band 1 and band 6, respectively.

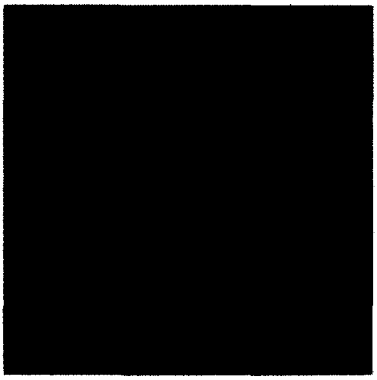

Figure 2. Nodule patterns with diameters of 0.4, 0.8, 1.2 and 2.0 mm, respectively.

Methods

Image quality assessment based on HVS

To assess the image quality based on HVS, an image was first decomposed into different frequency bands by band-pass filters, and the local contrasts of these filtered images were then calculated separately. The band-pass filters and band-limited contrasts were developed based on the frequency selectivity of the human visual system. The second procedure comprised the detection mechanism of the visual properties and was used to determine whether or not an image object with local contrast c could be detected by the human visual system. Fig. 1 depicts the procedures to assess the image quality based on human visual properties. The detection mechanism was described by the probability function which is expressed as follows [10]:

$$q_j(c_j(x,y)) = 1 - e^{-(c_j(x,y)/T_j)^{\beta}} \quad (1)$$

where $q_j(c_j(x,y))$ is the probability of detection at location (x,y) for frequency band j, $c_j(x,y)$ and T_j are, respectively, the band-limited local contrast and the threshold contrast of human eyes at band j, and β is the slope of the probability function and is about 3 for many experiments. The threshold contrast function $T_j(L)$ for frequency band j can be described by the following equation [11]:

$$T_j(L) = [a \times 2^j \exp(-b \times 2^j)\sqrt{1 + k\exp(b \times 2^j)}]^{-1} \quad (2)$$

with

$$a = 440\,(1 + 0.7/L)^{-0.2}$$
$$b = 0.3\,(1 + 100\,/L)^{0.15}$$
$$k = 0.06$$

and L is the background luminance in cd/m^2. According to the HVS model, the threshold contrast is a function of display luminance L [9], so Eq. (1) was modified as follows:

$$q_{j,L}(c_j(x,y)) = 1 - e^{-(c_j(x,y)/T_j(L))^{\beta}} \quad (3)$$

The contrast that results in a probability of 0.632 is defined as the threshold contrast for the image object. In this study, the probability of 0.65 was used as an index at which human eyes can detect an image. For each band, the probabilities of detection can be summarized as a single index for each band:

$$VQ(j,L) = \sum_{x=1}^{M}\sum_{y=1}^{N} q_{j,L}(c_j(x,y)) \Big/ M \times N, \quad j = 1,2,\cdots,k \quad (4)$$

where $VQ(j,L)$ is the visual detection index of an image object at band j with luminance level L. According to the threshold model for detection proposed by Sachs et al. [12], the ability to detect an image object is related to the frequency response of the object. The model describes that an image object can be just noticed if the contrast increases to the value that the VQ index for one frequency band of the object is larger than 0.65. From this model we could find the smallest contrast to detect a specific chest lesion pattern displayed on different devices and use it as an index to compare the image quality between devices.

For a window-leveled medical image, the background luminance should be approximately one half of the maximum luminance of the display device. Therefore, the background luminance levels for a regular light-box and computer monitor should be 1500 and 90 cd/m^2, respectively. To quantitatively investigate the effect of display luminance on the detectability of an image object displayed on light-box and computer monitor, simulated lung lesion patterns were used. Two patterns, pneumothorax lesion and nodule, were chosen. The pneumothorax lesion pattern was selected because research had indicated that radiologists were better able to discriminate pneumothorax on light-boxes than on computer monitors [13]. The visualization of the pattern is representative of subtle, high frequency pulmonary structure. As for the nodule, subtle lung nodules are frequently used to evaluate new thoracic radiographic systems. Wang and Gray [5] also indicated that the display luminance of the light-box affected the detectability of the nodule with small diameter on mammographic image

Nodule pattern

Lung nodules were simulated by digital superimposition of nodule shadows onto chest radiographs. According to Samei et al. [14], the contrast profile of a nodule can be described by the following equation:

$$c(r) = E\left(\frac{4.0}{D^4}r^4 - \frac{4.2}{D^2}r^2 + 1\right) \quad (5)$$

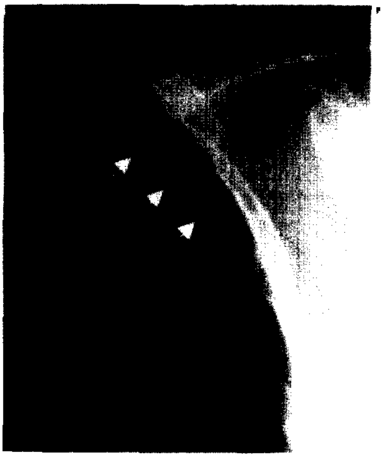

Figure 3. Test image with pneumothorax lesion. The arrows point out the location of the pneumothorax lesion.

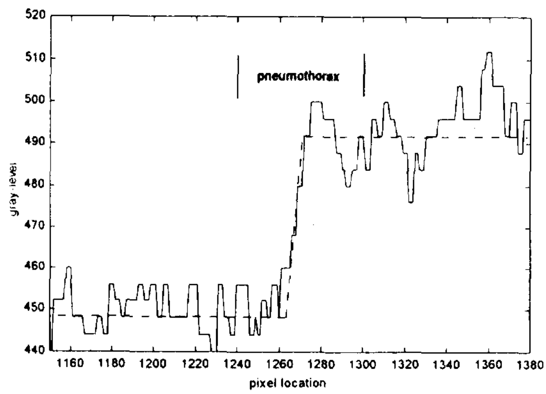

Figure 4. Cross-sectional profile of the image across the location of the pneumothorax lesion. To simulate the pneumothorax pattern, the dashed line was used as the waveform of the pattern.

where E is the contrast at the center of the nodule, D is the diameter of the nodule pattern and r is the distance to the center of the nodule. Fig. 2 is the image of simulated nodules with diameters 0.4, 0.8, 1.2 and 2.0 mm, respectively, with maximum contrast of 0.05.

Pneumothorax lesion pattern

A real case was used to obtain the simulated waveform of the pneumothorax pattern. A chest radiograph was digitized with a laser film digitizer (Lumiscan 150, Lumisys Inc.,). Fig. 3 is the image with pneumothorax lesion; the arrows indicate the location of the lesion. Fig. 4 is the cross-sectional profile of the image across the location of the pneumothorax lesion. The sharp edge between pixel locations range from 1261 to 1275 was recognized as the pneumothorax pattern. To simulate the waveform of the pneumothorax, the sharp edge of the pneumothorax pattern was preserved and other parts were set as the average gray-level of these parts. The dashed line in Fig. 4 was used as the waveform of the pattern. Unlike the nodule pattern has definite area, we assumed that the detection areas for the pneumothorax pattern, in the present study, were 0.1×0.1, 0.5×0.5 and 1.0×1.0 cm^2. To investigate the influence of display luminance on the detectability of the pattern, the contrast range of the pattern was chosen from 0.0025 to 0.075.

Table 1. Threshold contrasts of nodule with different diameters

	0.4 mm	0.8 mm	1.2 mm	2.0 mm
Light-box	0.0225(5)	0.01(4)	0.01(4)	0.01(3)
Monitor	0.03(5)	0.0125(4)	0.0125(4)	0.0125(3)

Note: Number in the parenthesis indicates the band with contrast larger than threshold

Table 2. Threshold contrasts for pneumothorax pattern under different detection areas

	Light-box	Monitor
1×1 cm^2	0.0375(2)	0.0388(2)
0.5×0.5 cm^2	0.0225(2)	0.0238(2)
0.1×0.1cm^2	0.0138(4)	0.0168(4)

Note: Number in the parenthesis indicates the band with contrast larger than threshold

Results

Fig. 5 shows the visual quality plots (VQPs) of the simulated nodule patterns where the diameter varied from 0.4 mm to 2.0 mm at a contrast of 0.0225. The contrast was selected because the probability of detecting these simulated nodule patterns displayed on light-box at this contrast was larger than 0.65. Solid and dashed lines represent the VQP at luminance levels 1500 and 90 cd/m^2, respectively. Top left of the figure depicts the VQP of the nodule with 0.4 mm diameter at the above viewing condition. The plot shows that the main component was located on the frequency band 5. At band 5, the detection probability was greater than 0.65 for the nodule displayed at 1500 cd/m^2 and was 0.4 at 90 cd/m^2. This implies that human eyes could detect the nodule with contrast of 0.0225 on light-box but could not detect the nodule with the same contrast on the computer monitor. The main component of the nodule with diameter of 0.8 mm (top right of Fig. 5) was on frequency band 4. The detection probability was larger than 0.65 at different display luminance levels. For diameters of 1.2 and 2.0 mm diameter, the main components were on bands 3 and 4. The VQP's for the nodules with diameters of 0.8 to 2.0 mm indicated that human eyes could detect these nodules displayed on light-box and monitor at a contrast of 0.0225, because the detection probabilities for them were all larger than 0.65. Fig. 5 also shows that as the diameter of the nodule increased from 0.4 to 2.0 mm, the main components of the frequency response shifted from band 5 to band 3. Fig. 6 depicts the probability of detecting the nodule with diameter of 0.4 mm at frequency band 5 as a function of the contrast and background luminance. The contrasts that resulted in a probability of 0.65 were 0.0225 for 1500 cd/m^2 and 0.03 for 90 cd/m^2. On the other hand, human eyes could detect nodule patterns clearly on both of the two display devices if the contrast of the nodule is larger than 0.03. Table 1 is the threshold contrast of nodules with different diameters. Only the threshold contrast of the nodule with diameter of 0.4 mm has large difference between light-box and computer.

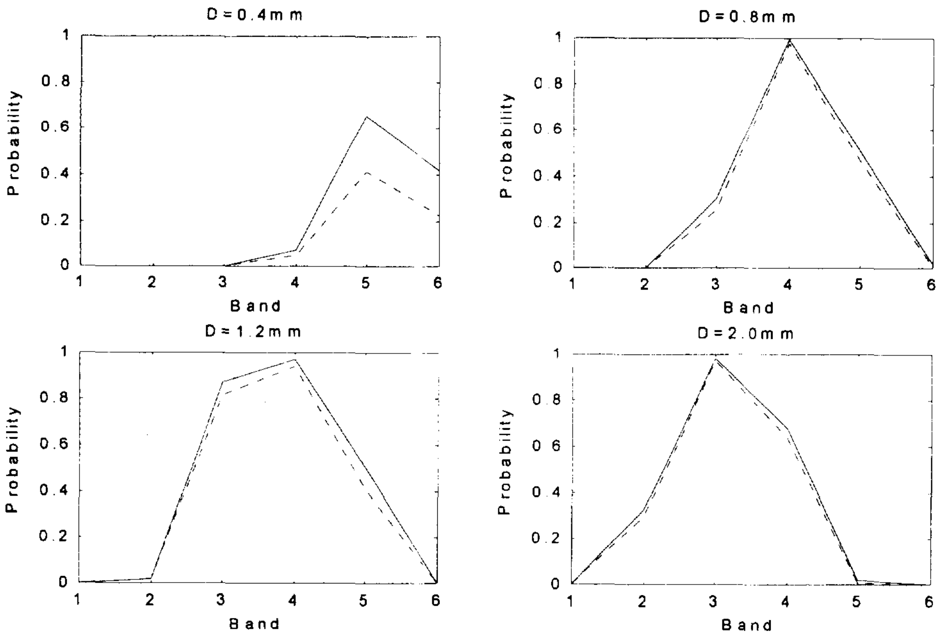

Figure 5. VQPs of the simulated nodule patterns where the diameter varied from 0.4 mm to 2.0 mm at the contrast of 0.0225. Solid and dashed lines represent the VQP at luminance levels 1500 and 90 cd/m^2, respectively. VQPs of the simulated nodule patterns where the diameter varied from 0.4 mm to 2.0 mm at the contrast of 0.0225.

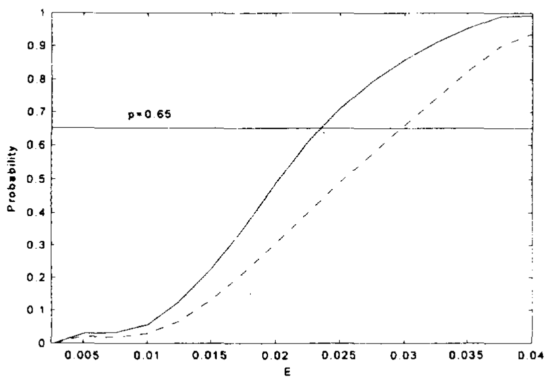

Figure 6. The probability of detecting a nodule with diameter of 0.4 mm at frequency band 5 as a function of the contrast and background luminance. Solid and dashed lines represent the VQP at luminance levels 1500 and 90 cd/m^2, respectively.

Fig. 7 is the VQPs of the pneumothorax patterns with contrast of 0.05 at the detection areas of 0.1 $\times$0.1, 0.5 $\times$0.5 and 1.0 $\times$1.0 cm^2, respectively. The figure indicates that as the detection area become smaller, the VQP of the pattern moves from band 3 to band 5. Table 2 is the threshold contrast under different detection areas. The threshold contrast for detection area of 0.1 $\times$0.1 cm^2 is the lowest contrast of the three areas. At this detection area, the threshold contrasts for the pneumothorax patterns displayed on light-box and computer monitor were 0.0138 and 0.0168, respectively. This result is agreed with our previous preliminary investigation of the detectability for the pneumothorax pattern displayed on light-box and computer monitor [8].

The local contrast of the pneumothorax pattern for band 4 at the specific position was depicted on Fig. 8. Fig. 8a and Fig. 8b are the local contrasts of the original and the contrast-reduced images. The arrow points out the location of the pneumothorax lesion. The local contrast for the pneumothorax lesion on Fig. 8b was 0.018, which was close to the theoretical result at viewing area of 0.1$\times$0.1 cm^2.

Discussion

This research provides a useful tool to estimate the influence of display luminance on the quality of the chest radiographic image displayed on light-box and computer monitor. Unlike qualitative descriptions of image quality on different display devices such as "good" or "degraded", the method finds out the influence of the luminance factor for different kinds of lesion patterns quantitatively. The results can also be used as a criterion in medical image enhancement methods. For example, the threshold contrasts were, respectively, 0.0225 and 0.03 for the nodule with diameter of 0.4 mm displayed on light-box and computer monitor. Therefore, for an observer to detect the same nodule on light-box and computer monitor, we can multiple the contrast of the image displayed on the computer monitor with a weighting factor of 0.03/0.0225 at the frequency bands 4 and 5. The threshold ratio can be used as a weighting function to enhance chest image displayed on computer monitor to make sure that the observer can detect the same information as displayed on light-box. For the pneumothorax pattern, the contrast ratio of 0.041/0.031 at frequency band 6 can be used as a criterion to enhance radiographic images with pneumothorax lesion.

For conventional ROC methods to analyze the quality of the medical image displayed on computer monitor and light-box, many radiographic images with low-contrast lesion patterns are required. However, the contrast range of the lesions

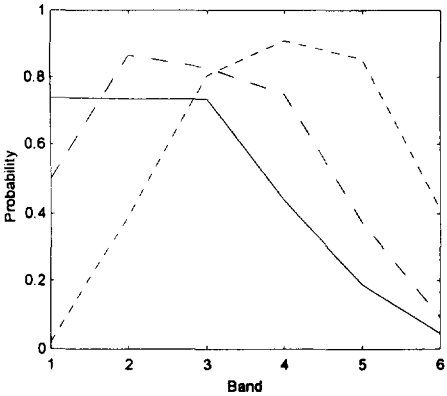

Figure 7. VQPs of the pneumothorax pattern with different detection areas. Solid, long-dashed and short-dashed lines present VQP for 1.0x 1.0, 0.5x 0.5 and 0.1x 0.1 cm^2, respectively.

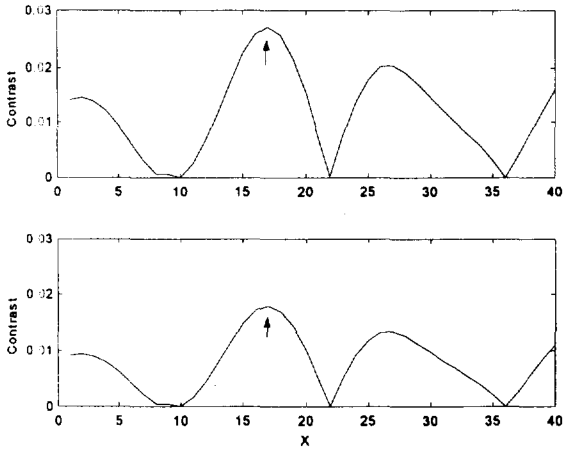

Figure 8. Profile of the local contrast at band 4 near the position of pneumothorax lesion. (a) Pneumothorax lesion that could be observed clearly. (b) Pneumothorax lesion that just cannot be observed on the computer monitor. The local contrast of the pneumothorax lesion is 0.018.

was not discussed and this could be the reason for the conflicting results about the detectability of the pneumothorax lesion on light-box and computer monitor [15-16]. The VQP method can be used to determine whether or not a disease pattern used in an ROC study is detectable on light-box but not on computer monitor. If a disease pattern can be detected on both display devices with any contrast, it cannot be used in an ROC test.

Conclusions

A quantitative method based on human visual properties to assess the image quality of light-box and computer monitor is presented. To compare the image quality between these two devices, two simulated lung lesions, nodule and pneumothorax, were used in the study. Two images are visually equivalent if the probabilities of detecting image objects on different display devices are the same.

The probability of detecting image object is a function of display luminance and frequency response of the object. The results showed that the luminance difference between light-box and computer monitor contributed to the degraded image quality on computer monitor. Image objects contains high frequency component has lower detectability on computer monitor than on light-box. Using the method, we could investigate the detectability of lung lesions on different display devices. The method can also be used as a criterion to enhance for the medical image displayed on computer monitor to have the same quality as on light-box.

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顯示於觀片箱及電腦螢幕之醫學影像品質之比較

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摘　要

以視覺系統爲基礎的影像加強法則已被用來探討顯示於觀片箱及電腦螢幕之醫學影像的品質。在本研究中，我們發展出包括視覺系統及亮度差異之影像品質評估方法，以模擬的肺結節及氣胸指出電腦螢幕之亮度對影像顯示品值的影響。0.4mm 直徑的節節在 1500 cd/m2 觀片箱及 90 cd/m2 電腦螢幕被偵測出時的亮度分別是 0.0225 及 0.03。當亮度是 0.0225，而節節直徑由 0.4 mm 到 2.0 mm 時，頻率響應的主要部分由帶 3 移到帶 5。對氣胸而言，當偵測面積減小時，主要部分則由較低頻帶移到較高頻帶。本研究指出若辨識疾病的主要依據是影像中的高頻訊號時，在電腦螢幕上偵測時會受到影響，觀片箱及電腦螢幕之亮度差異是主要的原因。

關鍵詞：視覺模型、影像品質、螢幕、觀片器、亮度

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