An applicability research on JND model

Tao Luo, Xuanqin Mou, Shaojie Tang, Ying Yang
(Xi'an Jiaotong University, Xi'an, Shaanxi 710049, P. R. China)

ABSTRACT

In medical radiation department, physician makes his diagnosis by surveying the images represented to CRT or film. Due to the inherent characteristic of radiograph, the pathology features always exhibit in the form of small size image signal with low contrast and noisy staining. To investigate the detectivity of human vision on these will help to solve the problem in what condition just-noticeable differences can be detected, and then to choose proper x-ray tube voltage and current to make x-ray exposure. In this work, a software of improved 4-forced choice experiment is developed. This experiment is performed to test observer performance in more than 600 groups respectively. By ROC analyzing, an exact range of some image parameters is detected to satisfy the Rose model. Some results are obtained as follows: when observer can detect JND with 50% TPF, the minimum contrast is approximately 1%, while background intensity is 20% of the maximum intensity and the value of k in Rose model approximately varies from 2 to 3 as target area changing. The minimum contrast decreases when the background intensity is above 20%.

Keywords: Image quality, Rose model, JND, Forced choice experiments

1. INTRODUCTION

1.1 Background

Human observer is elementary and important in various situations. In clinical diagnosis, human observer can evaluate the imaging system performance and detect abnormalities by surveying medical images on CRT or film. These pathology features always exhibit in the form of small size image signal with low contrast and weak edge. Being stained by quantum noise and fixed noise, the image quality is degraded which influence observer to make correct decision. Changing exposure condition, such as adopt lower tube voltage or longer exposure time, can obtain better image quality in X-ray imaging system. It is obvious that there is a compromise between image quality and radiation dose. Clinical diagnosis generally depends on several factors, including background intensity, signal area, contrast, and signal-to-noise ratio which represents image quality. The goal of study in this paper is to find out in what condition just-noticeable differences can be detected.

1.2 Theory

Previous work by A. Rose investigated the detectivity of human vision on these will help to solve the problem, and described a model representing human observer performance. The signal-to-noise ratio (SNR) for observer detection task can be written as:

$$SNR_{Rose} = C\sqrt{A\langle n_b \rangle} \qquad (1)$$

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Observer is required to detect a signal with area, A, against background with photon densities, $\langle n_b \rangle$. Signal contrast, C is defined as photon densities ration between signal and background.

Research by A. E. Burgess presented the correspondence between optimal matched filter and Rose model for human detection. Burgess pointed out there is limitation for valid of Rose model although its simplicity. Rose model is applied in these conditions: low-contrast signal, large photon densities and SKE/BKE task.

The signal-to-noise ratio Rose defined substantially represents the probability with which human observer can make correct decision. It has been proved that a disc can be detected in photon-noise-limited image when the value of signal-to-noise ratio is approximately 5 by Rose's experiments. Rose thoughts there was a threshold above which observer can detect signal with a certain true positive fraction.

The research on assessment of image quality is important for doctor to diagnose, and it is also useful for engineer to design selection of x-ray tube voltage and current in order to reduce radiation dose. As Rose model is rough and imprecise, our work aimed to find the just-detectable threshold and the precise condition to satisfy Rose model.

2. METHODS

2.1 Forced choice experiments

Psychophysical approaches to evaluate image quality can provide a subjective representation for human observer performance, including several common methods: contrast-detail experiments, resolution targets, constant stimulus, forced choice experiments, and so on. In forced choice experiments, signal always occurs in one of fields and human observer is required to make a choice in which field signal exists. Number of display fields in which signal possibly occurs may be 2, 4, 16 etc, known as two-alternative or multiple-alternative forced choice experiments. One advantage of forced choice experiments is reproductive. Another is avoiding actual psychological inherent noise of internal response. Definite significance can also be obtained from the results of forced choice experiments, evaluating observer performance.

2.2 Experiments design

2.2.1 Improved Rose model

Rose model is comfortable in the situation of low contrast, small signal and limited quantum noise. The photon noise which is considered in Rose model has a Poisson distribution. Therefore, $\sqrt{\langle n_b \rangle}$ represents the ratio of intensity of background to standard deviation of noise whose variance equal to the average cumulate photon number. For applying Rose model to our experiment , improved SNR formula is defined as follow:

$$SNR = \frac{C \cdot \sqrt{A} \cdot B}{\sigma_{noise}} \qquad (2)$$

The contrast, $C = |I_{signal} - B| / B$, where I_{signal} is the intensity of signal, and B is the intensity of background displayed on CRT. The area of signal region is denoted by A. Noise with standard deviation, σ_{noise}, has a Gaussian distribution in our experiments. Considering the number of photons is huge, Poisson distribution is approximately the same as Gaussian distribution with equal mean and standard deviation. Suppose intensities in signal region and backgrounds are equal, although they are generally different in fact. Such hypothesis is suitable especially in the case of low contrast. Then, the pixel noise variance is uniform in whole image.

2.2.2 Software design

Methods based on 4-alternative forced-choice experiments is used, in addition, we consider another possibility, the absent situation, to avoid prior knowledge error that observer know the target always exists in advance. Such improvement is much more agreed with actual case. In our experiments, disc signal of unity intensity need to be detected in a noise staining image. Software is designed convenient for adopting proper parameters, such as background intensity, contrast, signal area and intensity. Multiple shape of signal can also be selected for farther research.

In experiments, observer is required to choose one of four positions where signal exists, or 'no', means neither of positions signal exists. Position, signal shape and area are known before experiment. Observer keeps a distance about 50 centimeters before CRT screen. Once test image appears, observer must respond rapidly to position. Environment is in darkroom. Figure 1 shows the one of experimental images.

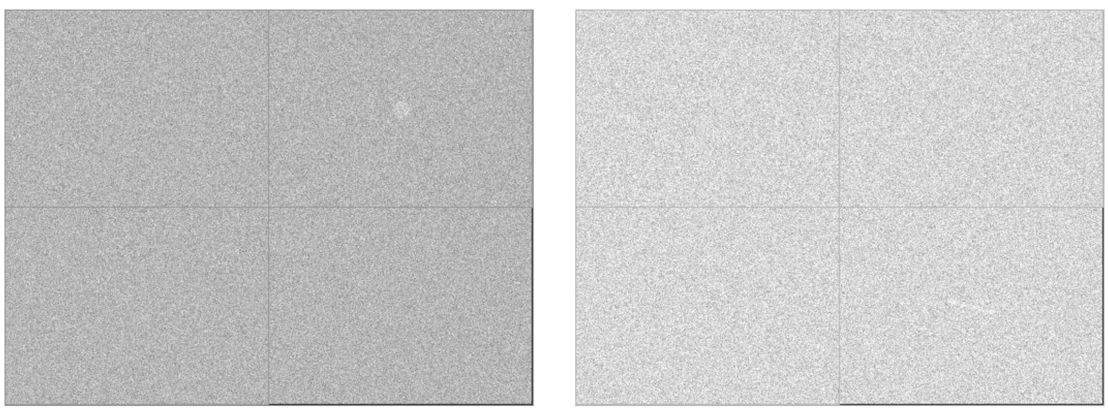

Figure 1. image on left is disc detection, image on right is rectangle detection

2.2.3 Experimental approach

To control test image quality, four parameters can be selected, including intensity, contrast, signal area and noise variance. Every group of experiments only change two parameters, such as contrast, CT and noise standard deviation, σ_{noise}. Only one parameter changes, such as σ_{noise}, the other parameter, CT is invariable at a time in one experiment. For every experiment, the threshold of σ_{noise} corresponding to 50% true positive fraction can be calculated, denoted by σ_{JND}, and the threshold of SNR can also be calculated from formula (2).

3. RESULTS AND DISCUSSIONS

3.1 JND calculation

Visual detection ability is evaluated by adjusting imaging parameters including background intensity, contrast, signal area and noise standard deviation. These four parameters corresponding to true positive fraction equals to 50% is considered as threshold on which observer can detect the just-noticeable differences. Threshold of SNR then is calculated from formula (2) according to thresholds of these parameters. For the experimental condition of low contrast, such as CT below 30%, there is a threshold for SNR, approximately 2.

Groups of experiments represent when signal area is 100 square millimeters, background intensity and contrast vary respectively; the thresholds of noise standard deviation are different whereas SNRs calculated from formula (2) are approximately invariable. The results are presented as follows in figure 1, figure 2 and figure 3.

Results from figure 1, 2, 3 fit the restriction of improved Rose model (formula 2). Compare figure 1 and 2, their contrasts both equal to 7.5%, the threshold of noise standard deviation increases according to background intensity increasing while SNR both approximately equal to 2. Compare figure 2 and 3, their background intensities both equal to 50% of the maximum intensity on CRT, the threshold of noise standard deviation increases according to contrast increasing while SNR both approximately equal to 2.

Figure 1 shows the relationships between true positive fraction (TPF) and noise standard deviation (sigma) , and relationships between TPF and SNR while background intensity (B) is 30% of the maximum intensity, signal area is 100 square millimeters, contrast is 7.5%. The curve of TPF rises upward when SNR varies from 1.3 to 4, and is flat when SNR above 4. We consider the SNR corresponding to 50% TPF as the threshold (SNR-threshold = 2.1298).

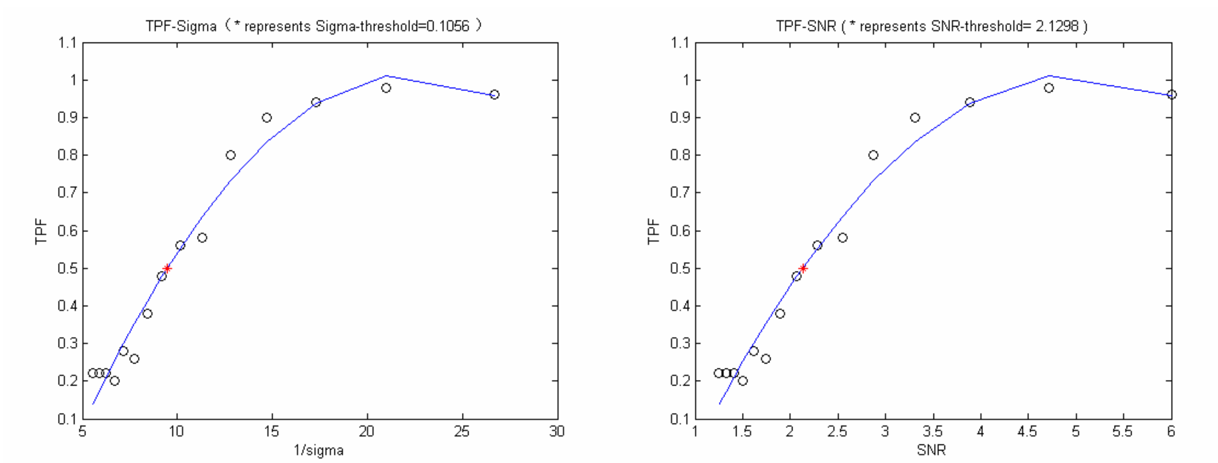

Figure 1. **A=100, B=0.3, CT=0.075**

Figure 2 shows the relationships between true positive fraction (TPF) and noise standard deviation (sigma) , and relationships between TPF and SNR while background intensity (B) is 50% of the maximum intensity, signal area is 100 square millimeters, contrast is 7.5%. The curve of TPF rises upward when SNR varies from 1.3 to 4.3, and is flat when SNR above 4.3. We consider the SNR corresponding to 50% TPF as the threshold (SNR-threshold = 1.9269).

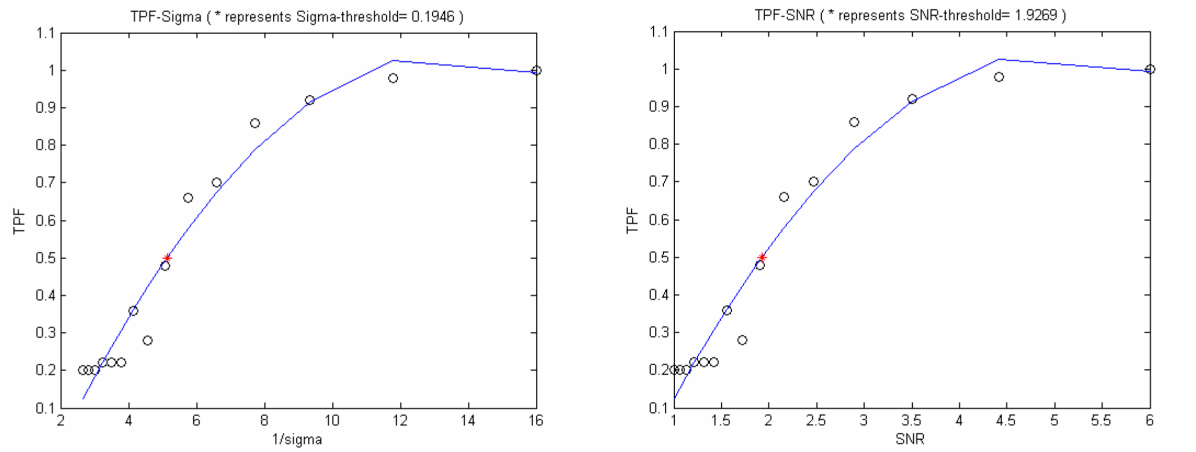

Figure 2. A=100, B=0.5, CT=0.075

Figure 3 shows the relationships between true positive fraction (TPF) and noise standard deviation (sigma) , and relationships between TPF and SNR while background intensity (B) is 50% of the maximum intensity, signal area is 100 square millimeters, contrast is 10%. The curve of TPF rises upward when SNR varies from 1.3 to 3.4, and is flat when SNR above 3.4. We consider the SNR corresponding to 50% TPF as the threshold (SNR-threshold = 1.9533).

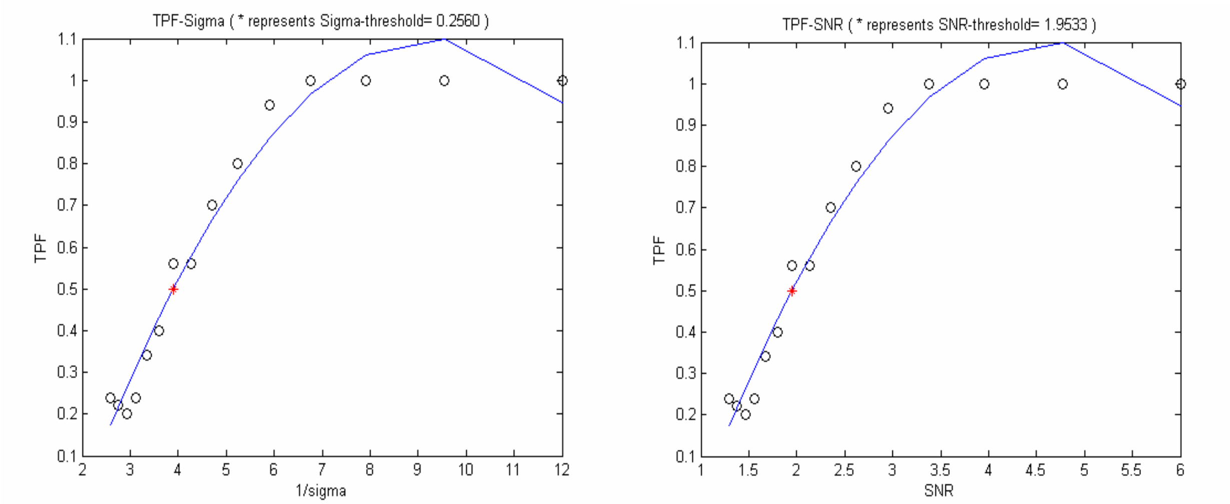

Figure 3. A=100, B=0.5, CT=0.1

3.2 Results compare

Results of group experiments are represented in table 1 while contrast, background intensity and noise standard deviation vary respectively. It shows that threshold of noise standard deviation increases if contrast or background intensity increases while signal area keeps invariable. It also shows that threshold of SNR approximately 2 no matter what parameters are selected as long as choosing fit signal area (about 100 ±50% square millimeter) and low contrast.

We also compare performance of different observers to verify universality. Results represented in table 2 explain the validity of improved Rose model although different observers experiment on different CRT.

Table 1 summarizes thresholds of noise standard deviation (Sigma-JND) and signal-noise-ratio (SNR-JND) while contrast (CT) and background intensity (B) change.

Table 1 Threshold compare

CT	A	B	Sigma-$_{JND}$	SNR$_{JND}$
0.05	100	0.5	0.1326	1.8853
0.075	100	0.5	0.1946	1.9269
0.1	100	0.5	0.2560	1.9533
0.05	100	0.3	0.0747	2.0087
0.075	100	0.3	0.1056	2.1298
0.1	100	0.3	0.1540	1.9486
0.05	100	0.1	0.0272	1.8360
0.075	100	0.1	0.0420	1.7874
0.1	100	0.1	0.0564	1.7737

Table 2 compares thresholds of noise standard deviation (Sigma-JND) and signal-noise-ratio (SNR-JND) of different observers.

Table 2 Observer compare

CT	SNR$_{JND}$-1	SNR$_{JND}$-2	SNR$_{JND}$-3	SNR$_{JND}$ -4	SNR$_{JND}$ -5
0.05	2.58	2.43			2.32
0.06	2.29	2.16	2.91	2.29	2.25
0.07	1.93	2.14	2.70	2.33	2.05
0.08	1.98	2.12	2.52	2.22	2.10
0.09	2.14	2.07	2.41		2.04
0.10	2.33	2.07	2.28	2.11	2.13
0.11	2.13		2.23	2.29	2.02
0.12	2.00		2.18	2.07	1.79

3.3 Linear relation

Figure 4 shows the relationships between CT and Sigma-JND. Curves are respectively represented the approximately linear relation with different background intensities. Slope describes the sensitivity between contrast and noise standard deviation, and greater slope value corresponds to more sensitivity. Positive intercept results from nonzero of contrast. It also can be seen that greater slope has a greater intercept.

Figure 5 shows the similar relationships between background intensity and Sigma-JND. Curves are respectively represented the approximately linear relation with different background intensities. Slope describes the sensitivity between background intensity and noise standard deviation, and positive intercept results from nonzero of background intensity.

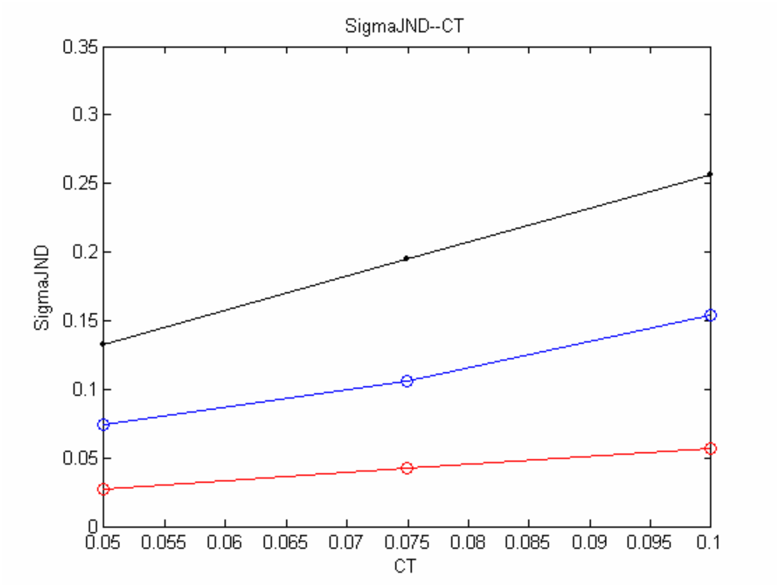

Figure 4 Relationship between Sigma-JND and contrast
Red line: B=0.1 Blue line: B=0.3 Black line: B=0.5

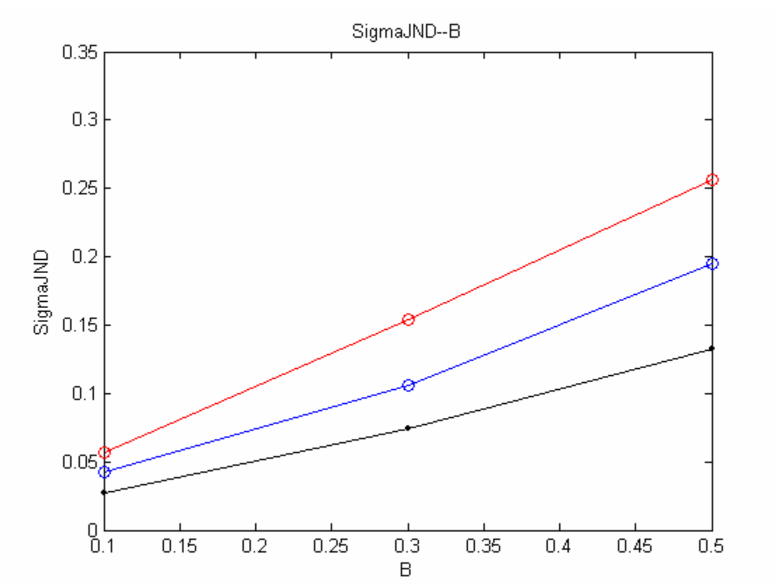

Figure 5 Relationship between Sigma-JND and background intensity
Red line: CT=0.1 Blue line: CT=0.075 Black line: CT=0.05

4. CONCLUSIONS

This paper based more than 600 groups of experiments sums up the just-detectable threshold of value k in rose model under different circumstance especially low contrast. It is useful to make a decision what parameters of imaging device should be adopted, including intensity of background, target area, contrast and noise variance, when observer can just detect the target. Our experiments improved the 4-forced choice experiments to export test image sequences to test human observers. The just-detectable threshold with 50% true positive fraction is calculated respectively in lots of circumstances. Our work confirms when the just-detectable threshold approximately equal to 2, while the lower limit of contrast is approximately 2%, the background intensity can vary from 0.1 to 12.38 cd per square meter, the target area can vary from 40 to 150 square millimeters.

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