Study on scan techniques dedicated for analysis of Computed Tomography (CT) system performance

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Abstract: This paper represents the subjective method and objective method, which were dedicated for the assessment of spatial and density resolution in CT system, and analyses the influence rule of scan parameters on the spatial and density resolution of CT image. The comparative study of the two methods was carried out in 3 ICT systems under the certain acquisition conditions, we found that the test result of subject method is significantly higher than the result of object method during the spatial resolution test, and then the test result and relationship between two methods was discussed. At last, this paper discusses the parameters of the best density resolution under the same power.

Keywords: spatial resolution, density resolution, test object, MTF, CDF, scan parameters, Noise, Positive correlation.

1. Introduction

Modulation Transfer Function (MTF) is the scientific means of evaluating the fundamental spatial resolution performance of an industrial computed tomography (ICT) system\textsuperscript{[1,2]}. It can be defined as the magnitude of Fourier transform of the edge response function, which are the response of an imaging system to an infinitesimal input signal. There are two methods which were mainly adopted to calculate the MTF curve of an industrial CT system, including the practical-MTF method and the disc phantom method.

The practical-MTF (p-MTF) method, uses line-pair phantom (see fig1)\textsuperscript{[3]}, was widely used in evaluation of the spatial resolution of ICT’s system on the advantage of simple and fast, while the disc phantom method, based on the technique which was proposed by ASTM E1695\textsuperscript{[4]}, has been proved to be convenient and accurate in the high spatial resolution industrial CT systems. In order to compare and evaluate the two methods, automatic analysis software tools were designed, and the corresponding phantom were also made.

Density resolution is an important parameter of CT system. Noise and density resolution had been found to have a statistically significant positive correlation\textsuperscript{[5]}. To research the relationship between the scanning parameters (tube voltage, tube current) and density resolution, the disc phantom method was introduced and applied in the practical testing of an industrial X-ray CT under certain acquisition conditions. The test method we adopt was CDF (contrast discrimination function) curve method, recommended by ASTM E1695. The parameters of the best density resolution under the same power were also discussed.

2. Materials and methods

The software we have developed is in capable of performing an automatic analysis on ICT’s image quality in terms of the spatial resolution and density resolution by using standard test object (see fig 2). The metal disc phantom (see fig 3) was prepared for disc phantom method, (aluminum disc: Φ 50×20mm for 420kV ICT, ferrumiron disc: Φ 100×20mm for 6MV ICT). The line pair phantom was prepared for p-MTF method (see fig 4), and the p-MTF’s calculation method is based on GJB 5312-2004.
Where $p\text{-MTF}[\text{line pair(i)}]$ is the practical MTF value for the frequency corresponding to the pattern group (i), $\Delta\mu$ is the amplitude value of the lowest frequency pattern, and $\Delta\mu_e(i)$ is the amplitude value for the higher frequency corresponding to the pattern group (i).

To research the relationship between the test results of different test methods, the comparative study of the two methods was carried out in 3 ICT systems under the same experiment condition.
3. Experiment

3.1 Spatial resolution approach

The experiments were carried out in three industrial CT systems. The line pair phantom and disc phantom were placed in the center of rotating table. Scan parameters were systematically varied respect to different industrial CT systems as outlined in detailed in Table 1.

<table>
<thead>
<tr>
<th>CT scan type</th>
<th>Tube voltage</th>
<th>Tube current/Synchronization frequency</th>
<th>Field of reconstruction</th>
<th>Slice thickness</th>
<th>Focus size</th>
<th>SDD/SOD</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>450kV ICT</td>
<td>400kV</td>
<td>2mA</td>
<td>70mm</td>
<td>0.25mm</td>
<td>1.9×1.9mm</td>
<td>632/520mm</td>
<td>5122</td>
</tr>
<tr>
<td>6MV ICT 1</td>
<td>6MV</td>
<td>150Hz</td>
<td>200mm</td>
<td>2mm</td>
<td>1.5×1.5mm</td>
<td>3104/2510mm</td>
<td>10242</td>
</tr>
<tr>
<td>6MV ICT 2</td>
<td>6MV</td>
<td>171Hz</td>
<td>200mm</td>
<td>1mm</td>
<td>2.0×2.0mm</td>
<td>3390/2714mm</td>
<td>40962</td>
</tr>
</tbody>
</table>

Fig. 5. The comparison between disc phantom method and practical-MTF method, the practical MTF method (•), and the MTF method (—)

3.2 Influence of scan parameters on X-ray CT performance

This experiment was designed to test the influence of tube voltage and tube current on density resolution and spatial resolution of different materials under the same power. And we choose the aluminium disc, acryl glass disc and titanium disc as test objects, the test methods we adopt to approach the spatial resolution and density resolution was recommended by ASTM 1695 and GJB 5311 [3]. The MTF and CDF curves describe the ability of spatial resolution and density resolution separately (see fig 6).
(a) Comparison of density resolution of Aluminum disc
(b) Comparison of spatial resolution of Aluminum disc
(c) Comparison of density resolution of acryl glass disc
(d) Comparison of spatial resolution of acryl glass disc
(e) Comparison of density resolution of Titanium disc
(f) Comparison of spatial resolution of Titanium disc

Fig 6 Influence of tube voltage and tube current on density resolution and spatial resolution of different materials under the same power.
4. Discussion

A strong advantage of practical MTF method is that it is simple and fast, that is also the reason that it was widely adopted to measure the spatial resolution of CT system, while the strong disadvantage is that it is difficult to make the line pair phantom (even worse prepared for the spatial resolution test in micro-CT), and the phantom need to be calibrated in specialized agency. But there are many advantages to use edge response function to calculate the MTF, first, the edge response is simple to measure, because the edge is easy to generate in image, second, all the edge response curves have the similar shape, and the third advantage is that MTF function can be directly found by taking one-dimensional FFT of the LSF (while the PSF to calculate MTF that must use two-dimensional Fourier transform).

Results from the two methods show a good correlation to the theoretical radio at the high frequency, but varied a lot in lower frequency. Spatial resolution is an important performance parameter of industrial CT system, the test result of both methods was influenced by the properties of test object and experiment conditions.

To test the influence of scan parameter on CT performance under the same power, we choose the aluminium disc, acryl glass disc and titanium disc as test objects, and adopt the methods recommended by ASTM 1695 and GJB 5311.[3] The results indicate that the MTF curve change slightly as the tube voltage and tube current changing under the same powder, but the CDF begin to change significantly at the same time (see fig 6). It also illustrates that the influence of tube voltage on density resolution is more significant than tube current.

5. Conclusion

(1) We have studied two methods that were widely used to measure the spatial resolution of ICT system in this paper, and analysis the test result of both methods. We found that the two methods proved to have a certain relationship between the test results, further more, the radio of test result of p-MTF method to disc phantom method should be equal to π/4 theoretically.

(2) The MTF curve change slightly as the tube voltage and tube current changing under the same powder, but the CDF begin to change significantly at the same time. It also illustrates that the influence of tube voltage on density resolution is more significant than tube current. In the practical application, improving the tube voltage properly generate better CT image under the same power.

Reference: