Optimization of the main parameters for the development of software-hardware scanning systems of digital X-ray radiography

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Abstract
At the present time among different types of systems of non-destructive radiation control scanning systems of digital radiography (SSDR) on the basis of detectors line are the most promising. While designing newly constructed SSDR there appears a problem of choosing their main parameters and characteristics (size and shape of the radiation source focus spot, size and shape of detectors aperture, focus distance, time of measuring radiation images etc.). The solution of the problem makes it possible to get a precise theoretical estimation of the potential opportunities of SSDR and thus to formulate valid technical requirements for their development. The number of tasks of optimal, by the criterion of maximum spatial resolution, choice of magnitudes of its main parameters considering digital filtration of radiation recording results has been solved.

Keywords: radiation control, digital radiography, line of detectors

1. Introduction

Nowadays among different types of systems of non-destructive radiation control scanning systems of digital X-ray radiography on the basis of detector line (SSDR) are one of the most promising.\cite{1, 2}. The systems have the following principle of work. Narrow (because of the slot collimation of the source) fan beam of X-ray (photon) radiation, coming through the object under control (OC) irradiates collimated line of detectors, signals of each of them are intensified and previously processed (integrated or recounted etc.) and then through analog-to-digital converters come in the computer where they are normalized and kept thus forming a relative line of samples of radiated OC radiation image. Then these samples are visualized on the screen creating the line of halftone image. Full halftone image is created by the single scanning of OC with the horizontal fan beam vertically or with the vertical beam horizontally.

2. Calculation of scanning systems of digital X-ray radiography parameters

While designing new SSDR there inevitably appears the problem of optimization of their main parameters. Its solution allows getting precise theoretical estimation of the potential abilities of SSDR and thus forming valid technical requirements for their development.

As a result of the conducted research the mathematical model of SSRD was developed and the following expressions were received for its special resolving capability (RC):

\[
R = \sup_{\mathcal{V}} \left\{ \prod_{i=1}^{n} \frac{\left| \sin \pi \nu_i b \right|}{\pi \nu_i b}, \frac{\sin \pi \nu^* g}{\nu^* g}, \frac{\nu^* g}{\nu \cos \alpha}, \frac{\nu^* g}{\nu \cos \alpha}, \frac{\sin \pi \nu^* \nu}{\nu^* \nu}, \frac{\nu^* \nu}{\nu \nu}, \frac{\nu^* \nu}{\nu \nu}, \frac{\nu^* \nu}{\nu \nu} \right\}
\]
\[
\cdot \cos(\pi \nu x) \cdot \cos \left( \frac{\nu y}{\cos \alpha} g \right) \cdot \text{rect}(\nu x) \cdot \text{rect}(\nu \frac{g}{\cos \alpha}) \cdot \\
\left\{ \sum_{m=-(M-1)}^{M-1} \sum_{k=-1}^{M-1} c(m,k) \cos \left[ 2\pi \left( \nu, m \nu T + \nu \frac{g}{\cos \alpha} \right) \right] \right\}^2 + \\
\left\{ \sum_{m=-1}^{M-1} \sum_{k=-1}^{M-1} c(m,k) \sin \left[ 2\pi \left( \nu, m \nu T + \nu \frac{g}{\cos \alpha} \right) \right] \right\}^2 \geq \frac{L \sqrt{\sum_{m=-1}^{M-1} \sum_{k=-1}^{M-1} c^2(m,k)}}{\sqrt{bgT}},
\]

if \( 0 < \frac{L \sqrt{\sum_{m=-1}^{M-1} \sum_{k=-1}^{M-1} c^2(m,k)}}{\sqrt{bgT}} \leq 1; \)

\( R = 0, \) if \( \frac{L \sqrt{\sum_{m=-1}^{M-1} \sum_{k=-1}^{M-1} c^2(m,k)}}{\sqrt{bgT}} > 1. \)

Here \( R - RC \ SSDR; \) expression, which is under the sign «inf», represents – contrast characteristic of SSDR; \( \sqrt{bgT} \) -relative threshold contrast (resulting from halftone image noise); \( \nu(\nabla \geq 0) \) - spatial frequency (subject to resolution of elements); \( \nu_x, \nu_y \) - spatial frequencies along the relevant coordinate axis; \( b \) and \( g \) – accordingly the length (dimension in the direction of scanning – along the axis \( Ox \)) and the width of aperture of a separate detector from the line; \( \alpha \) - half angle of the opening of operating beam of radiation;

\[
\text{rect}(z) = \begin{cases} 
1, & |z| \leq \frac{1}{2} \\
0, & |z| > \frac{1}{2} 
\end{cases}
\]

\( \nu \) - speed of scanning (movement) of OC;

\( T \) – time of registration of radiation (constant of the time of each of the time integrators); \( \{c(m,k)\} \) - pulse response of the digital filter satisfying the condition of normalization \( \sum_{m=-1}^{M-1} \sum_{k=-1}^{M-1} c(m,k) = 1 \); \( M \) – some natural number; \( (2M-1)^2 \) - the square of aperture (window) of digital filter (when \( M = 1 \) impulse response of digital filter will contain the only non – zero counting \( c(0, 0) = 1 \)); \( L \) – parameter of SSDR which considers: threshold attitude signal/noise (for elements under resolution, coefficient of amplitude disperse of electric pulses from the outlet of a separate line detector, radiation contrast of the elements under resolution, thickness and material of OC, effective energy of radiation behind OC, the angle of aperture of the operating beam of radiation, focal distance (distance from the source to the line of detectors along the axis of radiation beam), total quantum output of the source in a time unit in all the space, angle distribution of the source, efficiency of the registration of radiation by a separate detector from the line.
3. Results analysis

The results of the numerical problem solution of the main parameters optimization of SSDR on the criterion of its maximum RC are given in the Tables 1, 2, 3.

Table 1. Dependence of the maximum RC SSDR from parameter $M$

<table>
<thead>
<tr>
<th>$M$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{\pi L^2 \nu^3}{(\cos \alpha)^3} R_{\text{max}}$</td>
<td>0.612</td>
<td>0.906</td>
<td>0.919</td>
<td>0.936</td>
<td>0.954</td>
<td>0.975</td>
<td>0.978</td>
</tr>
</tbody>
</table>

Table 2. Dependencies of the optimal values of the parameters $b, g, T$ from parameter $M$

<table>
<thead>
<tr>
<th>$M$</th>
<th>$\frac{(\cos \alpha)^3}{L^2 \nu^3} b_{\text{opt}}$</th>
<th>$\frac{g_{\text{opt}}}{(\cos \alpha)^3 L^2 \nu^3}$</th>
<th>$\frac{v^{\frac{2}{3}} (\cos \alpha)^{\frac{1}{3}} T_{\text{opt}}}{L^2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.245</td>
<td>1.531</td>
<td>1.124</td>
</tr>
<tr>
<td>2</td>
<td>1.529</td>
<td>0.650</td>
<td>0.471</td>
</tr>
</tbody>
</table>

Table 3. Optimal values of counts $c(m, k)$ of the pulse response of the digital filter when $M = 2$

<table>
<thead>
<tr>
<th>$m$</th>
<th>$k$</th>
<th>-1</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td></td>
<td>0.0877</td>
<td>0.1249</td>
<td>0.0874</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>0.1212</td>
<td>0.1582</td>
<td>0.1209</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>0.0875</td>
<td>0.1248</td>
<td>0.0875</td>
</tr>
</tbody>
</table>

As we can see from Table 1, dimension $R_{\text{max}}$ increases insignificantly (by 7.9%) when changing parameter $M$ from 2 to 10. At the same time, dimension $R_{\text{max}}$ increases significantly (by 48 %) when changing parameter $M$ from 1 to 2, which speaks about the efficiency of digital filtration of the results of radiation registration. Considering this Tables 1 and 2 were drawn up for the optimal, that is getting maximum RC, values of the parameters $b, g, T$ and counts $c(m, k)$ of the pulse response of the digital filter.

Results which have been received (Tables 1, 2 and 3) can be taken as the basis when designing SSDR.

References