Cutting-edge technologies of medical radiography: tomosynthesis and double energy

A O Ustinov\(^1\) and A R Dabagov\(^2\)

\(^1\) LLC Scientific-technical center "MT" (STC-MT LLC), 143026, Moscow, Skolkovo, Russia
\(^2\) CJSC Medical Technologies Ltd (MTL CJSC), 105318, Moscow, Russia

E-mail: uao@mtl.ru, dar@mtl.ru

Abstract. The tomosynthesis technology is on the fringe of linear and computer tomography, combining high information capacity and low exposure. Diagnosing pathology of chest organs at early stages is complicated due to overlapping views of the lung and bone tissues. By using different X-ray energy ranges tissues with different absorption factors are separated and their separate images are received. This technology ensures that pathology is revealed at the early stage during routine screening.

Modern medical radiography can fulfill most clinical diagnostic tasks. Thanks to the flat-panel digital X-ray detector technology, the patient's exposure can be reduced significantly as compared to the traditional analog radiography. Traditional X-ray diagnostic methods have reached their limits. To increase medical practice efficiency further, we have to switch to using additional visualization methods, which include tomosynthesis and double-energy technologies.

In general-purpose radiography, the traditional linear tomography yields layer-by-layer images of the object, but only one slice is obtained during one pass of the X-ray generator. As a result, if a layer-by-layer image of the entire lungs is required the procedure is performed at least 10 times, which results in a considerable increase of the patient's radiation exposure and the procedure duration. The computer tomography method provides information about the entire chest volume, but increases the patient’s radiation exposure significantly \[1\].

The tomosynthesis technology is on the fringe of linear and computer tomography (CT), combining high information capacity (as compared to linear tomography) and low exposure (as compared to computer tomography). The X-ray source travels around the region of interest in an arc, making a series of exposures. The data on the geometric location of the source and the corresponding angled views make it possible to reconstruct the patient's internal volume.

There are a large number of tomosynthesis reconstruction algorithms:
- shift-and-add method (SAA);
- filtered back projection method (FBP);
- maximum likelihood estimation method (MLEM);
- adaptive statistical iterative reconstruction method (ASiR).

Each algorithm has its own advantages and shortcomings. SAA is one of the simplest algorithms, but the reconstruction quality leaves much to be desired. The algorithm adds views up layer by layer with a certain shift providing for the required height of the reconstructed layer. The FBP algorithm is...
the most popular one as of today, as it ensures the required image quality and is not resource-intensive. The main peculiarity of this algorithm is the choice of the filtering function. Its choice affects the image quality and presence of artifacts greatly. Iterative algorithms, MLEM and ASiR, are highly resource-intensive, which prevents their wide use in commercial systems [2].

Examples of reconstructing a calf’s head and the thorax of a Kyoto Kagaku PBU70 pediatric phantom using the FBP algorithm are presented below (figures 1, 2). The reconstructions were made using the Telekord-MT-Plus device made by CJSC Medical Technologies Ltd with the angle of 60° and in 30 views.

![Sample calf’s head reconstruction.](image1)

**Figure 1.** Sample calf’s head reconstruction.

![Sample thorax reconstruction.](image2)

**Figure 2.** Sample thorax reconstruction.

The Telekord-MT-Plus device allows conducting tomosynthesis studies with the column angulation angle and with the number of views up to 60. The operator sets the height of the region of interest in centimeters in accordance with the centerline of the object studied or the assumed location of the lesion. Besides, limit values for the reconstruction scope height and the slice thickness in millimeters need to be set. This ensures a high level of detail of the images received.
Diagnosing pathology of chest organs at early stages is complicated due to overlapping views of the lung and bone tissues. By using different X-ray energy ranges tissues with different absorption factors are separated and their separate images are received. This technology ensures that pathology is revealed at the early stage during routine screening.

Using the exponential law of radiation attenuation, a system of two equations for low (LE) and high (HE) energy levels can be written. The Rayleigh and Compton scattering components are negligible.

\[
I_{HE}^{DE} = I_{0}^{HE} \exp(-\mu_{soft}^{HE} t_{soft} - \mu_{bone}^{HE} t_{bone});
\]

\[
I_{LE}^{DE} = I_{0}^{LE} \exp(-\mu_{soft}^{LE} t_{soft} - \mu_{bone}^{LE} t_{bone}).
\]

where \( I \) and \( I_{0} \) are intensity values after and before passing the object (corresponding to the image brightness in terms of digital radiography), \( \mu \) is the attenuation factor, and \( t \) is the object thickness in centimeters.

Generally, the attenuation factor depends on the density of the electrons in the atom and the material atomic number.

\[
\mu(E) = \rho_{e} C_{P} \frac{Z^3}{E^4},
\]

where \( \rho_{e} \) is the density of the electrons in the material atoms; \( E \) – energy; \( Z \) – material atomic number; \( C_{P} = 9.8 \cdot 10^{-24} \). The atomic number for the soft and bone tissues is 7 and 20 accordingly.

The anode voltage used in medical X-ray equipment varies from 40 to 150 kV. The following ranges are chosen for the double-energy technology: 50–70 kV and 120–140 kV. This provides for spacing the energy beams, maintaining the required quality of radiation, and extending the X-ray generator’s useful life. Additional filtering is used to suppress low-energy components.

When solving a system of linear equations (1)–(3), the brightness values for soft and bone tissues can be represented as follows:

\[
I_{soft}^{DE} = \frac{I_{HE}^{DE}}{\omega_{s}};
\]

\[
I_{bone}^{DE} = \frac{I_{LE}^{DE}}{\omega_{b}}.
\]

here \( \omega_{s} \) and \( \omega_{b} \) are suppression factors for bone and soft tissues, equal to the ratio between the tissue attenuation factors for high and low energies. The values of the factors depend on the study environment, filtering, exposure parameters and the patient’s anatomic features. The following values were obtained experimentally: \( \omega_{s} = 0.25 \pm 0.10 \) and \( \omega_{b} = 0.60 \pm 0.10 \) [3].

Below, sample thorax images of a Kyoto Kagaku PBU50 phantom received using this technology by a Telekord-MT-Plus device made by CJSC Medical Technologies Ltd are presented (figure 3). Additional radiation filtering was used (1 mm Al and 0.2 mm Cu), with the grid (R12, 80 lp/cm) and the factors of 0.25 and 0.70.

Two types of parameters affect the final image quality: exposure and reconstruction parameters. Exposure parameters include: presence of the grid; type and value of additional radiation beam filtering; ratio between the radiation doses of both exposures. Reconstruction parameters include: suppression factors for bone and soft tissues; noise attenuation method used in the reconstructed image; noise attenuation factors.

Using modern tomosynthesis and double-energy technologies increases the information capacity of the study significantly and improves diagnostic capabilities at early stages. The main advantage of these technologies is the ability to use them with remote-controlled gantry tables with a flat-panel dynamic digital X-ray detector, without significant adaptation of the hardware, as well as with modern devices having two workstations.
Figure 3. Sample reconstruction of bone (left) and soft (right) tissues.

It is assumed that, when introduced into medical practice, double-energy and tomosynthesis technologies will in some cases make additional CT examinations redundant. This will help relieve CT rooms of the burden of routine examinations and make them accessible to more patients.

References
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