State of the Art and Development Trends of the Digital Radiography Systems for Cargo Inspection

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Abstract. Increasing requirements for technical parameters of inspection digital radiography systems are caused by increasing incidences of terrorism, drug trafficking and explosives via variety of transport. These requirements have determined research for new technical solutions that enable to ensure the safety of passengers and cargos in real-time. The main efforts in the analyzed method of testing are aimed at the creation of new and modernization of operated now systems of digital radiography as a whole and their main components and elements in particular. The number of these main components and elements includes sources of X-ray recording systems and transformation of radiometric information as well as algorithms and software that implements these algorithms for processing, visualization and results interpretation of inspection. Recent developments of X-ray units and betatrons used for inspection of small- and large-sized objects that are made from different materials are deserve special attention. The most effective X-ray detectors are a line and a radiometric detector matrix based on various scintillators. The most promising methods among the algorithms of material identification of testing objects are dual-energy methods. The article describes various models of digital radiography systems applied in Russia and abroad to inspection of baggage, containers, vehicles and large trucks.

1. Introduction

The terrorism is one of the principal dangers for the society in XXI century. In support that we can mentioned scaled terroristic acts on transport (2001 – September 11 attacks in USA; 2009 – 2010 – Moscow Metro bombing, Nevsky Express bombing; 2011 – Domodedovo International Airport bombing) [1, 2]. As relation in Russia and aboard there is generated a whole scientific and technical area named «anti-terroristic diagnostics» to secure the passenger operations and freight service [2–6].

The systems for anti-terroristic diagnostics (inspection of cargo) solve a wide spectrum of tasks: explosive, toxic and radioactive material detection, and also all kinds of explosive devices and killing agents [2].

All types of the Custom Equipment can be divided on the following big groups [6]:

1. The technical means and systems to detect the objects by its visually perceptible forms (by outward appearance, internal structure image, thermal image and etc.) are:

− optical magnifying devices (magnifying glass), inspection mirrors, technical endoscopes, borescopes and videoscopes;
− inspection television systems;
− infrared imagers;
− inspection of radiation.

2. The technical means and systems to detect the objects by indicative of material properties (by conductivity, permeability or permittivity, density, chemical composition, presence of nonlinear electromagnetic properties, radioactive radiation and etc.) are:
− metal detectors;
− nonlinear radars;
− ultrasonic echolocation devices;
− narcotic and explosive detectors (dreyfspektrometry, gas analyzers, radiation gamma quantum and corpuscular imaging devices, kits chemicals, immunochemical diagnostic tools);
− radiation monitoring devices.

3. The technical means and systems to detect the objects by features work of mechanisms and electronic devices (by distinctive sound, vibration, electromagnetic radiation and etc.) are the radio radiation detection equipment (including the side electromagnetic radiation), acoustic and vibro-acoustic signals.

4. Integrated Inspection Systems providing combining the functions and possibilities of two or more types of inspection equipment in one system are: metal detectors with built-in sensor of the ionizing radiation, mobile robotic systems and other combined system.

As follows from numerous publications (for example, [5–10]), currently among different kinds of the inspection systems the digital radiography system (DRS) are occupied one of the dominant positions. The description of its state of the art, the practical usage and also the further development trends would be presented below.

2. The digital radiography systems for cargo inspection

The term «digital radiography» means a set of methods of non-destructive radiation testing and diagnostics for whose the radiation image of the inspected object (IO) is converted on some stage into a digital signal. Further this digital signal is stored in computer memory and redistributed to the two-dimensional array of the measured data, which can be digitally processed (contrast enhancement, scaling, dissection, smoothing etc.) and, finally reproduced on display as a half-tone image, directly perceived by the operator [11, 12].

The main efforts of the radiation inspection experts are directed to create a high-performance sources and detectors of the ionized radiation, and also to develop algorithms and software to process the results of detection of radiation. For example, Non-destructive Testing Institute of Tomsk Polytechnic University (NDT-institute TPU) with company «Foton» created the following sources of the ionized radiation [13]:
− charged particle accelerators – betatrons MIB – 7,5D and MIB – 9D (Shtok–T) used to the trucks inspection;
− X-ray machines RAP 160-2D, RAP 200-4D, RAP 300-4D used to the cars inspection.

In the same article [13] it was noted that in the inspection DRS to record the transmitted radiation most often used three base types of detectors:
− fluorescent screens with CCD camera;
− fluorescent screens with photodiode matrix;
− scintillation crystals in combination with photodiode array.

In NDT institute of TPU there was developed the original specialized software «Diada» to visualize the internal structure of IO, which was used in different DRS specifically – to detect prohibitive electronic components of printed-circuit boards.

In work [14] there is analysis of requirements for the betatron’s bremsstrahlung radiation dose rate meters (monitors), designed to use in the inspection systems and to inspect large size articles. The designed monitors have the radiation resource no less 10000 hours, work in wide temperature range from – 20 to +50ºC and provide measurement of dose rates from 0.05 to 50 R/min. The geometrical sizes of one monitor for energy 9 MeV are 30×25×285 mm^3.

In some inspection tasks it is necessary to identify the material of the inspected object. It can be done to identify the IO class which is prohibited or strictly regulated to cross-border movement or to transport by air. For the material identification there are applied methods using the ionized radiation sources. The dual energy methods (DEM) are most widely used [15] and based on the evaluation of X-ray attenuation for two sources with specially selected maximal energies. There are existed also some modifications of this method: twice X-raying – for two different X-ray tube voltages (it corresponds to two effective radiation energies); single X-raying with the radiation recording by two placed one after the other (along the beam path) detectors and etc. By this method the IO components can be divided by its effective atomic number (Z_{eff}) and the color image [16] is generated by color identification palette, where:

"light-weight" materials with Z_{eff} <10 have shades of orange;

"middle-weight" materials with 10< Z_{eff} < 20 have shades of green;

"heavy-weight" materials with Z_{eff} >20 have shades of blue.

The work [15] estimates contribution of the various components to the integrated measurement error of the effective atomic number of the homogenous IO by the dual energy method for energy range below 200 keV. It was shown that the largest contribution to the measurement error of the effective atomic number is due to the maximum energy deviations in the X-ray radiation spectra.

The work [17] researches the high-energy realization of DEM. This realization is based on the IO prescan by narrow beams of the high-energy X-ray radiation with two maximal energies, on the generation of two digital radiographs, on the further separate estimation of contributions of the Compton scattering and the effect of pair production into X-ray attenuation and into the generation of the identification parameter image.

For the mass-produced portable betatron MIB 4.5/7.5 in work [18] a series of calculations to estimate the different physical factors influence on the identification quality were carried out. The following factors were considered: maximum energy deviations of the high-energy X-ray radiation from the nominal values; the radiation, scattered within IO; the radiation, scattered within construction of inspection system. Studies prove the needs to consider mentioned factors for the expection system design with material identification option by the dual high-energy method.

The work [19] describes a new algorithm to identify materials for the X-ray luggage inspection system, used in airports and strategic locations. The algorithm is based on the DEM and the spectral analysis of the digital radiographs.

In order to improve the accuracy of automatic recognition of nuclear and explosive materials in inspected objects (e.g., containers in seaports) using DEM and high-energy X-ray sources (with a maximum energy of 2.5 MeV to 9 MeV) [20] it proposed to carry out X-raying OK by three fan-beams from three sources. Thus, each beam is formed from a single radiation source and is recorded on the proper line of detectors.

The work [21] made a simulation of the container inspection system, comprising as the radiation source accelerator 4 MeV/9 MeV and 960-detectors array with the detector aperture size 6×6 mm^2. To identify the materials there was used DEM realization based on the proposal that detectors have a function of the energy discriminator, i.e. there is an electronic separation of the impulse flows on the detector's output. Developed as a result of research methodology permit to identify the following materials: tissue-equivalent plastic, Al; Fe; Ag.

The authors in [16, 22] studied the questions more informative radiographs due to the X-ray registration passed through the IO for two, three and more energy ranges. Three-energy X-ray images of the inspection objects with the effective atomic number from 7.08 to 8.07 were generated. The material recognition precision by the effective atomic number was about 5 % when using detectors with type scintillator-photodiode on base of scintillator ZnSe(Te).

The work [23] reports that «Rapiscan Systems» company developed the inspection system on base the linear accelerator for 9 MeV to detect a special nuclear material within freight containers. This system uses the two step inspection. On the first stage (main scanning) the container is checked quickly and fully by images, generated by use two independent detector's arrays: conventional main array with the high space resolution and the array with «rough» energy resolution. Those two detector arrays are used to detect high-Z objects, i.e. the objects with high atomic number (such as lead, tungsten, uranium), which can be potential protective materials or special nuclear materials. On second stage, container areas, whose were identified as high-Z, rechecked. This is accomplished by X-raying those areas by X-ray beam and by recording the secondary radiation (fast neutrons, delayed gamma rays), which generated if high-Z area contains special nuclear material.

The work [24] presents the description of experience of practical use DRS, intended for cargo container inspection to detect a special nuclear material. Reportedly, in particular, that scan speed is about 45 cm/s. The build system has a similar structure with one from [23].

The DRS on base the linear accelerator 3 MeV / 6 MeV to detect contraband in aircraft containers is described in work [25]. To accelerate the suspicious cargo detection the container radiography is doing under several directions (multi-view). The detector array with the detector aperture size 6×6 mm^2 was used. The scan speed was about 0.2 m/s. The time to acquire the container images in two orthogonal views was about 40 s.

3. Summary

1. The inspection DRS development is carried out mainly by the X-ray source and detector enhancement, and also by the enhancement of algorithm and software for digital data processing.
2. The inspection performance can be significantly increased by use two-step procedure – the main scanning all object and the subsequent rescan of selected suspicious areas.
3. To improve the inspection efficiency of DRS it is advisable use the multi-angle-raying (multi-view) with simultaneous use several radiation sources and detector arrays.
4. To improve the reliability of the unauthorized objects detection it is necessary further development as methods to improve the space resolution of DRS, and as the material identification methods (dual energy methods and its versions).

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