FAST NEUTRON AND GAMMA-RAY INTERROGATION OF AIR CARGO CONTAINERS

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SUMMARY

Dual beam fast neutron and gamma-ray radiography is particularly attractive for screening cargo as it can be used to provide high resolution images of cargo composition with scan times of less than one minute. The Commonwealth Science and Industrial Research Organisation (CSIRO) has developed a dual-beam radiography technique that combines fast (14 MeV) neutron and gamma-ray or X-ray radiography (FNGR). This FNGR technique is much more efficient than methods that measure secondary radiation and has much better material discrimination sensitivity than the alternative dual high-energy X-ray technique. A full-scale prototype FNGR scanner was trialed by Australian Customs Service to screen air cargo at Brisbane International Airport in 2005/6. The trial of the scanner demonstrated the material discrimination capability of the technology and its ability to make concealed organic materials more obvious. CSIRO and Nuctech Company Limited have recently developed a new version of the scanner suitable for commercial deployment (the AC6000XN Air Cargo Scanner) that combines a 14 MeV fast neutron radiography system with dual-energy X-ray radiography [1]. The X-ray system uses a 6 MeV LINAC X-ray source and Binocular Stereoscopic imaging with much better spatial resolution than the scanner trialed at Brisbane airport. The improved resolution, combined with Binocular Stereoscopic imaging, allows complex cargo images to be separated into multiple layers, making it easier to identify threat items. The first commercial unit of the new scanner was commissioned in Beijing in mid-2009.

A detailed description of the work can be found in the recent paper by Sowerby et al at the IAEA “International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators”, Vienna, 4 – 8 May 2009 [1]. A full list of publications is given at the end of this report.
SCOPE OF PROJECT UNDER COORDINATED RESEARCH PROJECT

Under the terms of the Research Agreement between the IAEA and CSIRO, the specific activities include:

- Evaluation of Fast Neutron and Gamma-ray Radiography (FNGR) for the detection of contraband in consolidated air cargo
- Enhancement of FNGR technology as it relates to the examination of air cargo with a view to improved contraband detection and to reduce the incidence of false positives and false negatives.
- The assessment of neutron generator and detector systems for FNGR.

RESULTS OF PROJECT UNDER COORDINATED RESEARCH PROJECT

1. Evaluation of Fast Neutron and Gamma-Ray Radiography (FNGR) for the Detection of Contraband in Consolidated Air Cargo

A full-scale prototype FNGR scanner was trialed by Australian Customs Service to screen air cargo at Brisbane International Airport in 2005/6. The trial of the scanner demonstrated the material discrimination capability of the technology and its ability to make concealed organic materials more obvious. The installation at Brisbane International Airport allowed the technology and associated business processes to be tested in a real time operational environment. The trial of the scanner at Brisbane was critical to understanding the potential of the technology and to show up both its strengths and areas that need further development. Strengths included the material discrimination capability of the technology, its ability to make hidden organic materials more obvious and the scanning speed. Consolidated cargo was scanned in less than two minutes once the cargo is at the scanner, thus allowing high volumes of cargo to be screened rapidly.

Comparative tests of the Brisbane scanner against two commercial single-beam X-ray scanners on a representative selection of air cargo showed that the FNGR scanner had a detection capability comparable to the best of the available X-ray scanners, despite having significantly lower spatial resolution and without the multi-view capabilities of one of the X-ray systems. It was assessed that with improved spatial resolution (5 mm detectors or smaller)
and multi-view capability, the CSIRO Air Cargo Scanner has the potential to significantly outperform current commercial X-ray air cargo scanners.

In 2007, CSIRO signed a joint venture agreement with Nuctech Company to develop and commercialise a new scanner incorporating CSIRO's neutron technology and Nuctech's X-ray technology. The first commercial unit of the new air cargo scanner (the AC6000XN Air Cargo Scanner) has been commissioned in Beijing and is undergoing a program of trials to demonstrate the technology to prospective customers.

2. Enhancement of FNGR Technology as it Relates to the Examination of Air Cargo

The single greatest obstacle to the detection of small threat items in air cargo is image complexity. Air cargo is generally significantly more cluttered than sea freight and this places heavy demands on analysts, particularly when the time for image interpretation is short. Four key enhancements are discussed below.

a) Improved spatial resolution

The CSIRO Reference Scanner [1] was used to assess and compare techniques for improving spatial resolution, including super-resolution and reducing detector sizes. Laboratory trials have shown that the use of small (5×5 mm) gamma detector elements provides better spatial resolution than super-resolution methods using the 10 mm detector elements used in the Brisbane scanner. For the 20×20mm neutron detector elements, super-resolution provided an adequate improvement in resolution and maintained the detector count rates necessary to allow rapid scanning. The resulting higher resolution images were found to be a significant aid in understanding complex, high-clutter cargos.

b) Multiple views of the cargo

Multiple views of the same cargo can prove very advantageous in resolving complex images. The conventional approach is to use dual radiation sources and detector arrays to provide orthogonal views, usually from the side and from above. However, operators of these systems generally struggle to assimilate two very different views when they were only given a short time to analyse images. A simpler alternative is to use binocular stereoscopic imaging. The
system implemented in the commercial AC6000XN scanner utilizes a single X-ray source and multiple folded X-ray detector arrays. This system allows complex cargo images to be separated into multiple layers, making it easier to identify threat items.

c) Imaging software

Mathematical algorithms have been developed to deliver sharp, crisp images and to allow materials in cargo to be accurately identified. The images are corrected for dead-time (neutron scan) and ADC dark-noise (X-ray scans), non-functioning detector elements, geometric distortion and variations in the output intensity of the X-ray and neutron sources. The X-ray and neutron images are then accurately registered and non-linear spatial filters are applied to simultaneously improve sharpness whilst reducing statistical “noise” or speckle. From the raw neutron and X-ray images, a suite of new images are calculated for user analysis. The primary output combined both the neutron and 3 MeV X-ray data to produce a coloured image that shows shape, density and composition information. Secondary outputs are the 6 MeV X-ray grey-scale images, which offer maximum penetration through thick cargos, and the segmented binocular stereoscopic images which shows the cargo as a series of depth-based ‘layers’.

d) Managing the human-machine interface

It is important to present the image analyst with easy-to-use yet powerful software to allow him/her to rapidly and accurately identify suspicious items inside cargo containers. In the FNGR scanners, images are displayed using custom image visualisation software, designed to allow image analysts to rapidly manipulate and interpret the images to detect contraband items. In addition to the usual display functions (brightness and contrast adjustment, histogram equalisation and inverse mode), the software allows the user to rapidly compare different views of the same cargo. A material identification tool indicates possible substances that are compatible with the $R$ value of a point in the image selected using the computer mouse. To help resolve the problem of overlapping items, a background stripping tool can be used to mathematically remove over- or underlying material and provide a better $R$ value estimate for an object of interest.
3. Assessment of Neutron Generator and Detector Systems for FNGR

a) Assess Neutron Generators

The key requirements for a neutron generator for FNGR are: (a) intense output to allow rapid scanning (preferably $>10^{10}$ neutrons/sec); (b) sufficient energy to penetrate thick cargos; (c) small active volume to preserve image resolution; (d) high reliability; (e) high availability; (f) ease of operation; (g) reasonable capital and running costs; and (h) safety considerations.

The Brisbane scanner used a Thermo MF Physics A-711 DT neutron generator that can continuously produce up to $10^{10}$ neutrons/second of 14 MeV neutrons. The generator was typically operated to produce about $5-6\times10^9$ neutrons/second. The A-711 was successfully used by Australian Customs in the Brisbane facility from December 2005 until the end of the Brisbane trial in March 2007. Over this period a total of over 800 hours on-time were accumulated on the neutron generator tube.

The AC6000XN scanner uses the same neutron generator as that used in the Brisbane scanner but with a new D-711 digital controller. The digital controller allows software based on/off control that does not require scanner operators to get involved in complex neutron generator start-up and control procedures. Alternative generators will be assessed for future scanners.

b) Neutron detectors

The AC6000XN scanner uses similar neutron detector arrays to those developed by CSIRO for the Brisbane scanner. The neutron detectors are configured to be parallel to one X-ray beam. Four columns of 20×20 mm neutron detectors with offset detector elements are used and mathematical reconstruction techniques (super-resolution methods) employed to calculate an image at higher resolution than the pixel size.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the key role of Nuctech staff working with CSIRO to develop the commercial AC6000XN scanner. The authors also acknowledge the financial support and assistance of the Australian Customs Service and the Department of Prime
Minister and Cabinet in the development and testing of the Brisbane Airport and Reference scanners.

REFERENCE


PUBLICATIONS (2005-2009)


