



HAL
open science

Creating a reference database of cargo inspection X-ray images using high energy CT of cargo mock-ups

Selina Kolokytha, Alexander Flisch, Thomas Luthi, Mathieu Plamondon, Stefan Hartmann, Wicher Visser, Adrian Schwaninger, Diana Hardmeier, Marius Costin, Caroline Vienne, et al.

► To cite this version:

Selina Kolokytha, Alexander Flisch, Thomas Luthi, Mathieu Plamondon, Stefan Hartmann, et al.. Creating a reference database of cargo inspection X-ray images using high energy CT of cargo mock-ups. *Multimedia Tools and Applications*, 2018, 77, pp.9379-9391. 10.1007/s11042-017-4937-x . hal-04559005

HAL Id: hal-04559005

<https://hal.science/hal-04559005>

Submitted on 25 Apr 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Creating a Reference Database of Cargo Inspection X-ray Images Using High Energy CT of Cargo Mock-ups

Selina Kolokytha [1], Alexander Flisch [1], Thomas Lüthi [1], Mathieu Plamondon [1], Stefan Hartmann [1], Wicher Visser [2], Adrian Schwaninger [2], Diana Hardmeier [2], Marius Costin [3], Caroline Vienne [3]
[1] Center for X-ray Analytics,
Empa - Swiss Federal Laboratories for Materials Science and Technology,
8600 Dübendorf, Switzerland
E-mail: selina.kolokytha@empa.ch
[2] Center of Adaptive Security Research and Applications (CASRA),
8050 Zürich, Switzerland
[3] CEA LIST, Department of Imaging & Simulation for Non-Destructive Testing,
91191 Gif sur Yvette, France

Frank Sukowski [4], Ulf Hassler [4], Irène Dorion [5], Andrea Canonica [6], Eric Rochat [6], Ger Koomen [7], Micha Slegt [7]
[4] Fraunhofer Institute for Integrated Circuits IIS, Development Center for X-ray Technology (EZRT),
90768 Fürth, Germany
[5] Smiths Heimann S.A.S. (SH),
94405 Vitry sur Seine, France
[6] Swiss Federal Customs Administration (FCA),
3003 Bern, Switzerland
[7] Dutch Customs Laboratory (DTCA),
6401 DN Heerlen, The Netherlands

Abstract—Customs continue to use a wide range of technology in protecting against terrorism and the movement of illicit trade and prohibited imports. The throughput of scanned vehicles and cargo increases and just keeps on growing. Therefore, the need of automated algorithms to help screening officers in inspection, examination or surveillance of vehicles and containers is crucial. In this context, the successful collaboration between manufacturers and customs offices is of key importance.

Facing this topic, within the seventh framework program of the European Commission, the project ACXIS “Automated Comparison of X-ray Images for cargo Scanning” arose. This project develops a reference database for X-ray images of illegal and legitimate cargo, procedures and algorithms to uniform X-ray images of different cargo scanners, and an automated identification of potentially illegal cargo.

Keywords—National security; X-ray tomography; X-ray applications; Computed tomography; Reconstruction algorithms; simulation; High energy physics instrumentation computing; Inspection

I. INTRODUCTION

Within the grand scheme of security, border control, and specifically the screening of border traffic cargo, has seen increasing focus in recent years. The fiscal integrity and security of the movements of goods across these borders are the responsibility of Customs Administrations. Accordingly, they are also expected to have a positive impact in the economic competitiveness of their respective nation. Given the status of today’s world of trade as well as the related unlawful cargo transport threats, effective and efficient border controls are essential for increasing the wealth of nations and improving the welfare of people. The increasing number of

cargo transported through borders requires innovative inspection procedures. In this direction, automatic detection in cargo screening constitutes an important role.

Within the project ACXIS, cargo screening developments are made in supporting the inspection officers’ work of illegal cargo and threat detection. More specifically, ACXIS develops automated target recognition (ATR) functions to analyse X-ray images of cargo screened at border crossing points (land, air or sea).

These functions are designed to continuously self-improve through a central reference data base. This database contains X-ray images of illegal and legal cargo, and is designed to be manufacturer independent. All these database images, particularly the ones containing threats, constitute a significant tool for the training of screening officers and also for machine learning methods in automated detection algorithms.

II. HARDWARE SET-UP AND OPTIMISING

In order to image illegal cargo mock-ups, laboratory x-ray scanners were used at Empa, CEA and EZRT. The Dutch and Swiss Customs Administrations used their own commercial cargo scanners, such as Smiths Heimann, Rapiscan and Nuctech systems.

The X-ray source used for the data acquisition at Empa was a portable dual energy 4 and 6 MeV linear accelerator; with a focal spot size of 2 mm (Fig. 1). Certain modifications were applied on the existing high energy CT at Empa, in order to optimise the system for this project. First, rails were placed on the linear accelerator and the detector towers to allow changing the source-to-detector distance up to 5.4 m. Then, the CT

detector were replaced by a newly designed line detector consisting of 20 modules with 32 channels each, made of 30 mm deep CdWO₄ scintillators with a pitch of 4.6 mm (X-Scan LCS 4.6, from Detection Technology) (Fig. 2). Careful design and work was carried out in the detector assembly in reducing X-ray scattering. Additionally, new lead and tungsten source collimators were installed to shape the beam according to the detector geometry. An X-ray filter, specially designed, was fitted between the primary and secondary source collimators to flatten the intensity of the X-ray beam over the full detector width (approximately 3 m).



Fig. 1. ACXIS laboratory setup of cargo container imaged by linear accelerator (left) and new detector (right; hidden behind container).

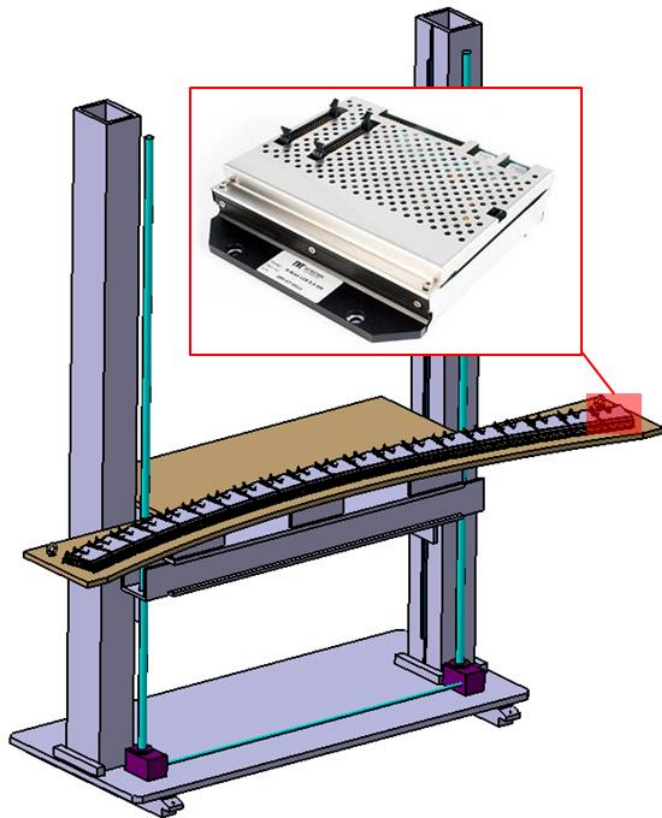


Fig. 2. 3D CAD of the . without the casing, to allow visualisation of the individual detector modules. Th fitted on adjustable towers. Close up

The laboratory scanner built at CEA consists of a linear accelerator, a line detector and a translation table. The scanning geometry was chosen to match the commercial scanners, namely a horizontal translation of the object, using a vertical detector line. The linear accelerator is a Varian Linatron M9A model, delivering 5, 6 and 9 MeV with a maximal dose rate up to 30 Gy/min. The focal spot size is specified to less than 2 mm in diameter. The detector is made of 10 X-Scan LCS 4.6 modules, assembled on a straight line. A lead collimator is used in front of the active area and the backside is shielded by 5 mm of lead.



Fig. 3 Laboratory setup at CEA

The translation table has a second plate that can be tilt with $\pm 15^\circ$, as shown in fig. CEA2. This option was used for mock-up objects for which different incident views were needed. Tilting the objects is equivalent to placing them at different heights in a full container, hence several combinations of various positions were operated more easily.



Fig. 4 Translation table with tilt in the setup of CEA

III. REFERENCE DATABASE: AN INTEGRATION

One of ACXIS key goal is the creation of a reference database of realistic X-ray images of both legitimate and illegal cargo. Such a database is essential for teaching screeners and for providing assisted detection techniques of threats with the use of dedicated algorithms. To construct this database, we highly rely on historic images provided by custom officers. However, the number of threat images acquired through real detections remains limited and needs to be increased by additional threat images obtained through simulation. A very important aspect for this project is that all the pre-mentioned images must have a standard format so that images originating from different systems can be incorporated.

A. Threat Images from Mock-Up Scans

Based on risk analysis conducted by the Customs administrations, threat objects and their locations in the container were identified. Following their recommendations, a set of mock-ups was created with real threat items and simulants, combined with common goods (Fig. 5). These were scanned using laboratory systems, and some with a cargo scanner, chosen as reference.

For some illegal items the incidence of the X-ray paths through the object largely influences the produced image. Therefore mock-up X-ray scans were performed with different object tilts so that the best projection can be selected depending on the vertical position of the object in the container

B. Threat Images from Simulation Software

The main objective of the mock-up scans was to enlarge the variety of threat images. For the same purpose, simulation tools were also used in order to generate X-ray images from 3D models of various types of threat items (e.g. weapons).

The geometry acquisition, source spectrum and detector parameters of the high energy scanner are defined in the simulation software. 3D models of different weapons are then loaded in the software environment and multiple projections are created (Fig. 6).



Fig. 6. 3D CAD model (left) and simulated X-ray projection (right) of a weapon.

C. Merging Threat Images with Historic Ones

To efficiently generate X-ray images for the database one solution is to artificially merge X-ray projections of illegal cargo and X-ray images of freight containers with legal goods. The basic principle of X-ray imaging is the measurement of the X-ray photons which are attenuated when traversing matter. This process is modelled by the Beer-Lambert law, which can be approximated as follows:

$$I_{\text{det}} = I_0 e^{-\sum_{i=1}^N \mu_i x_i} \quad (1)$$

Where I_{det} is the beam intensity at the detection point after traversing N different materials, I_0 is the beam intensity at the initial point, μ_i and x_i are respectively the linear attenuation coefficient and the width of each material. According to (1), the beam intensity at the detector point corresponds to the combination of the attenuation due to each material successively penetrated by the X-ray beam. It can be decomposed as:

$$I_{\text{det}} = \underbrace{I_0 \cdot e^{-\mu_1 x_1} \dots e^{-\mu_j x_j}}_{I_{\text{bg}}} \cdot \underbrace{e^{-\mu_{j+1} x_{j+1}} \dots e^{-\mu_N x_N}}_{e^{-\mu_{\text{th}} x_{\text{th}}}} \quad (2)$$

Where I_{bg} is the beam intensity attenuated by the background (legitimate cargo without threat constituted of j materials) and the parameters μ_{th} and x_{th} represent the characteristics of the threat element (constituted of $N-j$ materials).

Then, by injecting in (2) the additional measure of the incident beam intensity attenuated by the threat I_{th} it comes:

$$I_{\text{det}} = I_{\text{bg}} \cdot \frac{I_{\text{th}}}{I_0}, \quad (3)$$

with:

$$I_{\text{th}} = I_0 \cdot e^{-\mu_{\text{th}} x_{\text{th}}} \quad (4)$$

According to (3), we can combine pixel to pixel the attenuation of the threat (threat image acquired as described in earlier subsection) to the grey value of the legitimate image to create an image of illegal cargo (Fig. 7).

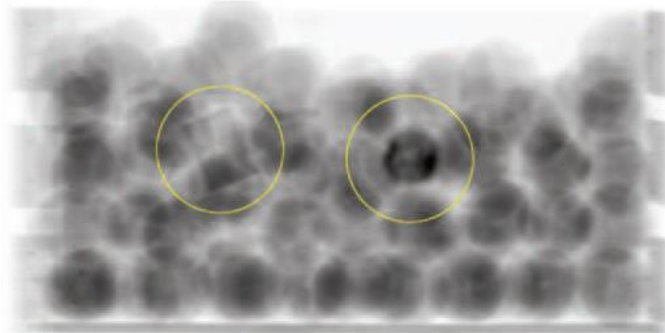


Fig. 5. Photograph of a container of apples containing hidden Plastex and hand grenade (above). X-ray image of this threat container (below).

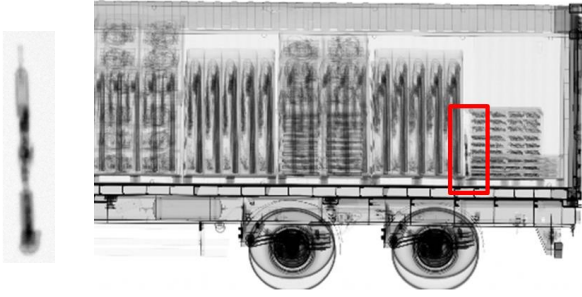


Fig. 7. Simulated image of a weapon (left) inserted in a legitimate cargo to create artificial illegal cargo images (right).

D. Creating a Unified X-ray Image Standard

Upon visual inspection of X-ray images, the human brain can easily adapt to different systems, regardless the different parameter variations such as geometric deformations, textures, and levels of contrast or noise. This is not equally the case for automatic algorithms.

Given the large variety of X-ray scanners installed at border checkpoints, it is important that the acquired images are similar in terms of the permitted parameters. As such, standardising these images enables an increase in the automatic detection performances. Therefore, all X-ray data is converted into a standardised format and stored in a database, along with the results of the ATRs and useful annotations (Fig. 5). This standardisation enables the comparison between scans originating from different X-ray imaging systems. The database is loaded with a large array of reference material, and new scans are continuously integrated.

Geometric adaptation is very challenging since projecting a complex load from distant view angles generates different distortions in the resulting image. Due to the high number of possible arbitrary X-ray projections of illegal cargo, an alternative method was followed in order to avoid scanning radiographic images from many different angles: acquiring 3D CT scans of mock-ups and then artificially generating multiple X-ray projections. This approach selects the most similar ray paths and makes use of the standardised container dimensions giving satisfactory conversion results (Fig. 8).

Similarly, scanners with very different energy spectra such as mobile systems equipped with 2.5 MeV sources and stationary ones using 9 MeV accelerators produce very different images in terms of contrast and image quality. Based on this analysis, it is not relevant to convert all scanner images to a unique reference configuration but for creating a homogeneous database, we propose to standardise images acquired with systems of energy in the range 4 MeV to 9 MeV. The strategy for the adaptation of contrast is based on the use of X-ray images of step wedges of different materials, which give a unique response curve for a given system. Using these images, we express, for a given thickness of material, the attenuation value of one system as a function of another. The equation of this curve corresponds then to the contrast

conversion function, which is applied after the geometric conversion.

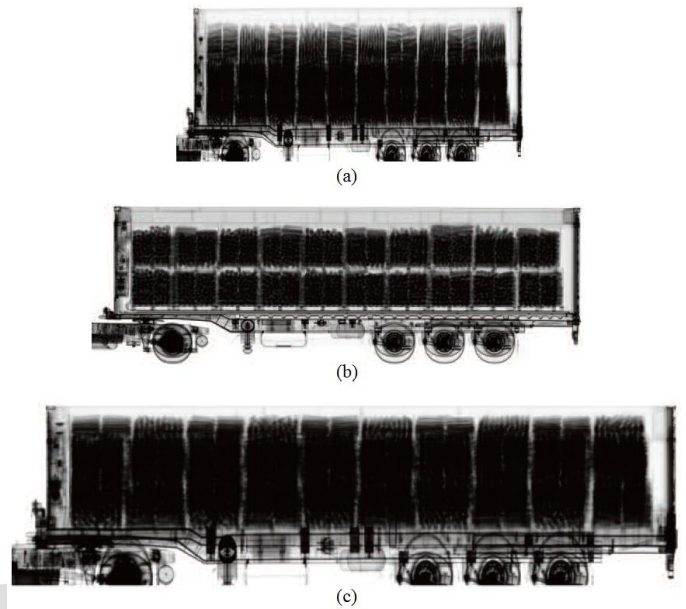


Fig. 8. Real container scan with Euromax (a) and SH-HCVS (b) scanners. The Euromax scan was converted to the HCVS format (c).

Finally, several noise reduction algorithms were evaluated in order to select the best one to reduce the noise to the level of the reference scanner, without affecting the image quality (e.g. the texture or the sharpness).

IV. CUSTOMS OFFICERS TRAINING

The purpose of the integrated reference database is also to be used in educational, computer-based training (CBT) programs aimed to train and qualify customs officers in X-ray screening competence. The web-based software, developed for this purpose, simulates the image analysis environment (Fig. 9). Its interface features a variety of supportive functions such as zoom and image enhancement functions to mimic real-work-conditions. In addition, ATR functions are simulated and can display frames that indicate suspect goods have been detected. The officers, to their discretion, can choose to take this information into consideration, or to ignore it when they believe that the ATR function has generated a false alarm. The waybill information is also provided to the officer, regarding the container contents.

The CBT software incorporates both training and testing modes. For example, it displays a container image and asks the screening officer whether and where suspect goods are present. Following each image inspection, the officer is given feedback. When a screener correctly reports that an X-ray image contains an item that does not match the waybill or is prohibited, the response is counted as a hit. If an incorrect answer has been given, the response is categorised as a false alarm. After the analysis of the screener, and if an illegal item is present in the image, a feedback window displays the object picture and X-ray image. The training time and further details

of the simulated scenario can also be examined. Finally an additional feedback is provided upon completion of a training session.

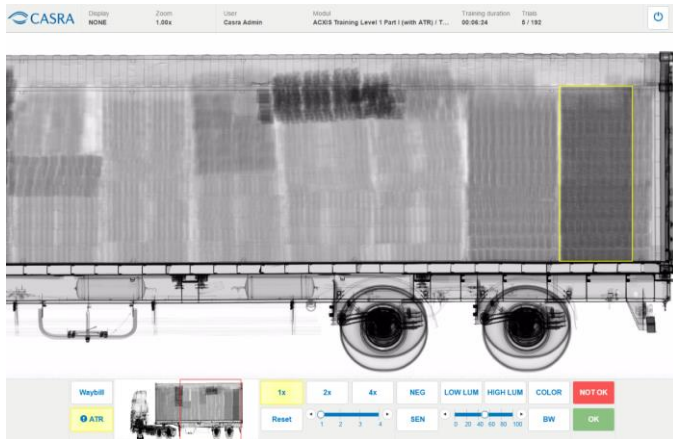


Fig. 9. The user interface of the X-ray inspection simulator to train screening officers.

V. CONCLUSIONS

Project ACXIS develops a reference database for X-ray images of illegal and legitimate cargo, procedures and algorithms to uniform X-ray images of different cargo scanners, and an automated identification of potentially illegal cargo.

The created integrated reference database is also used for customs officers training and evaluation. The developed software incorporates ATR functions, which together with the impact of the systematic computer-based training is currently assessed through a validation study. It is expected that the study results confirm that ATR and training improve the

effectiveness of border controls and reduce the amount of time necessary to successfully inspect cargo.

ACKNOWLEDGMENT

The ACXIS project is supported by the European Commission through the Seventh Framework Programme (FP7).

REFERENCES

- [1] S. Michel, S. M. Koller, J. C. De Ruiter, R. Moerland, M. Hogervorst, and A. Schwaninger, "Computer-based training increases efficiency in X-ray image interpretation by aviation security screeners," in *Security Technology, 2007 41st Annual IEEE International Carnahan Conference on*, 2007, pp. 201–206.
- [2] G. Chen, P. Bjorkholm, T. R. Fox, Z. Wilson, and X. Bonsergent, "X-Ray Cargo Inspection: Status and Trends," in *Application of Accelerators in Research and Industry: Twentieth International Conference*, 2009, vol. 1099, pp. 570–573.
- [3] E. A. Miller, J. A. Caggiano, R. C. Runkle, T. A. White, and A. M. Bevil, "Scatter in cargo radiography," *Appl. Radiat. Isot.*, vol. 69, no. 3, pp. 594–603, 2011.
- [4] S. Michel, M. Mendes, J. C. de Ruiter, G. C. Koomen, and A. Schwaninger, "Increasing X-ray image interpretation competency of cargo security screeners," *Int. J. Ind. Ergon.*, vol. 44, no. 4, pp. 551–560, 2014.
- [5] A. Bolfiging and A. Schwaninger, "Measurement formulae for image-based factors in x-ray imagery," VICOREG Technical Report, 2007.
- [6] A. Bolfiging, T. Halbher, and A. Schwaninger, *How image based factors and human factors contribute to threat detection performance in X-ray aviation security screening*. Springer, 2008.
- [7] F. Sukowski, T. Fuchs, and P.-M. Keßling, "High energy X-ray CT of freight containers," in *Fraunhofer Symposium Future Security. 4th Security Research Conference 2009*, 2009, pp. 277–281.