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

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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 offers’ 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 OPTIMISATION

In order to image illegal cargo mock-ups, laboratory x-ray scanners were used at Empa, CEA and EZRT (XXL-CT). 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
The laboratory scanner built at CEA consists of a linear accelerator, a line detector and a translation table (Fig. 3). 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.

The translation table has a second plate that can be tilt with ±15°, as shown in Fig. 4. 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.

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).

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:

\[ I_{\text{det}} = I_0 e^{-\sum_{i=1}^{N} \mu_i x_i} \]  

(1)

Where \( I_{\text{det}} \) is the beam intensity at the detection point after traversing \( N \) different materials, \( I_0 \) is the beam intensity at the initial point, \( \mu_i \) 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:

\[ I_{\text{det}} = I_0 \cdot e^{-\mu_1 x_1} \cdot e^{-\mu_2 x_2} \cdot \ldots \cdot e^{-\mu_N x_N} \]  

(2)

Where \( I_{\text{bg}} \) is the beam intensity attenuated by the background (legitimate cargo without threat constituted of \( j \) materials) and the parameters \( \mu_{th} \) 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:

\[ I_{\text{det}} = I_{\text{bg}} \cdot \frac{I_{th}}{I_0} \]  

(3)

with:

\[ I_{th} = I_0 \cdot e^{-\mu_{th} x_{th}} \]  

(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).
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 of 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 permissioned 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. 8). 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. 9).

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.

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).
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.

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.

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REFERENCES