Image recognition for x-ray luggage scanners using free and open source software

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Abstract. This paper describes the status of a currently ongoing research and development project that proposes the implementation of a system to be connected to x-ray luggage scanning equipment used by the Airport Security Police (*Policía de Seguridad Aeroportuaria*, PSA), having as main objective to automatically recognize images obtained in real time from the scanners to alert the x-ray machine operators or screeners about those identified as threats (explosive devices, firearms, etc.) Technical instructions and source code of a web-service and auxiliary scripts developed for the evaluations were published on github in order to enable interested researchers, developers and other potential contributors to repeat or reproduce the training and testing summarized in this paper with freely available image data-sets.

Keywords: luggage control, x-ray images, airport security, explosive detection, firearms detection, image recognition, computer vision, deep neural networks, machine learning, TensorFlow library.

1 Introduction

Given the recent advances in computerized image recognition [1,6,7] and the availability of free and open-source software [12,13] that facilitates the practical application of these techniques [14,15,16], the project proposes the implementation of a system that, connected to the x-ray luggage scanning equipment currently in use by the PSA (Argentine Airport Security Police, or *Policía de Seguridad Aeroportuaria*), will have as main objective to automatically recognize images obtained from the scanners to alert the operator about images identified as threats (explosive devices, firearms, knives, other weapons or dangerous items, etc.)

Although a fair amount of literature has been published regarding this subject (for example [1,2,6,7,8,9,10]), including papers dealing with the recognition of x-ray images in search of threats such as those mentioned above, the data-sets or sets of images used in most of these publications are not in the public domain. Another factor that makes it difficult to reproduce published results is the availability of necessary software or the capacity to develop it.

On the basis of the above, in order to confirm the feasibility of the DGT project, and to be able to determine if the threshold or margin of precision of the estimates that the system would generate are acceptable, tests were performed on two data-sets; sample images obtained from PSA scanners, as well as on other sets of images in the public domain [3,4]. Regarding software, the decision was made to implement the classification software using Google's free and open source software library form machine learning, TensorFlow [12,13].

This paper will include information about how the experimental models were trained and evaluated. Two of the data-sets used in this work are based in a freely downloadable one in the public domain; other, such as the one composed of sample images included by the manufacturer of x-ray luggage scanners from the PSA, are reached by redistribution constraints.

The technical instructions, source code of the web-service for classification of images that are passed to it as input, and general auxiliary scripts, will be published on github [18] in order to permit interested third parties to repeat the tests with the freely available sets of images.

2 Training and evaluation

As already stated, we used TensorFlow, an open-source, free-to-use library for the implementation of machine learning techniques in Python and C++ programming languages. Our goal was to test the performance of recognition of images obtained online from luggage scanners in order to alert or alarm, if applicable, about images identified as threats.

Regarding data-sets, with focus on explosive devices detection, images included by the manufacturer into x-ray luggage scanners used in the PSA were obtained and adapted to compose the first data-set. A second and third data-sets, aiming at the detection of firearms and knives, were composed with images obtained from a public x-ray images database that can be used free of charge for research and educational purposes.

2.1 TensorFlow library from Google

As stated in [12], TensorFlow is an open-source software library for Machine Intelligence. It is library for numerical computation using data flow graphs. Nodes in the graph represent mathematical operations, while the graph edges represent the multidimensional data arrays (tensors) communicated between them. The flexible architecture allows the deployment of computation to one or more CPUs or GPUs in a desktop, server, or mobile device with a single API. TensorFlow was originally developed by researchers and engineers working on the Google Brain Team within Google's Machine Intelligence research organization for the purposes of conducting machine learning and deep neural networks research, but the system is general enough to be applicable in a wide variety of other domains as well.

As stated in [15], modern object recognition models have millions of parameters and can take weeks to fully train. Transfer learning is a technique that shortcuts a lot of this work by taking a fully-trained model for a set of categories like ImageNet, and retrains from the existing weights for new classes. Inception-v3 model from Google was trained for the ImageNet Large Visual Recognition Challenge using the data from

2012. This is a standard task in computer vision, where models try to classify entire images into 1000 classes, like "Zebra", "Dalmatian", and "Dishwasher".

In this work the final layer of the Google's pre-trained Inception v3 model was retrained using this technique. To perform transfer learning the final classification layer of the network was removed and the next-to-last layer of the Convolutional Neural Network (CNN) extracted, in this case a 2048 dimensional vector. More information regarding this approach could be obtained, for example, from [19,20, 21,22].

2.2 PSA luggage scanners data-set

Example images included in equipment currently in use by the PSA were extracted to gather a data-set containing x-ray images classified in three groups: explosives, firearms, and general (negative) luggage.

After discarding duplicated and not suitable images, clipping of images with to increase the number of negative samples, rotation at different angles, changes in size, quality, etc.; the quantities per class obtained are shown in table 1.

Table 1. PSA luggage scanners data-set.

Explosive artifacts	4800
Firearms	2160
General luggage (negative)	1500

Example images of this data-set are shown in figures 1 and 2. Firearms class include images of pistols and revolvers; 357, 9mm, 38, 22; from different manufacturers (Magnum, Bersa, Colt, etc.) Explosive materials include C-4, Dynamite, Semtex, etc., with different switches or timers, batteries, and initiators.

This data-set objective was primarily used to train a model that would recognize explosive devices.

As summarized in [11], one of the primary weapons of choice for terrorists and lone wolf attackers has been the Improvised Explosive Device, or IED. These dangerous, homemade devices are typically constructed from common household items making them rather inexpensive to build.

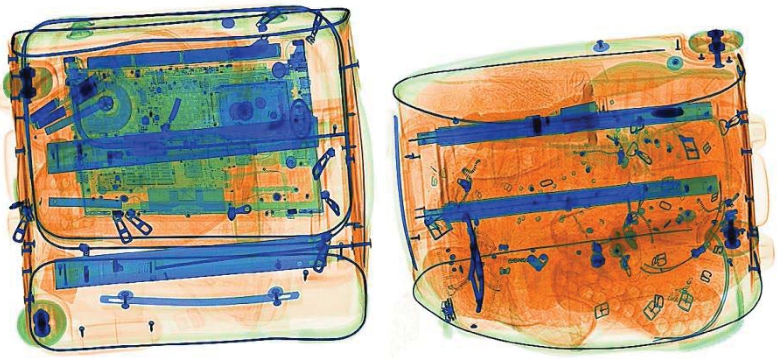

Fig. 1. Sample image from a PSA scanner showing luggage containing a laptop (left) and another one showing shoes, sneakers and slippers (right). These images are included in the “negative” class.

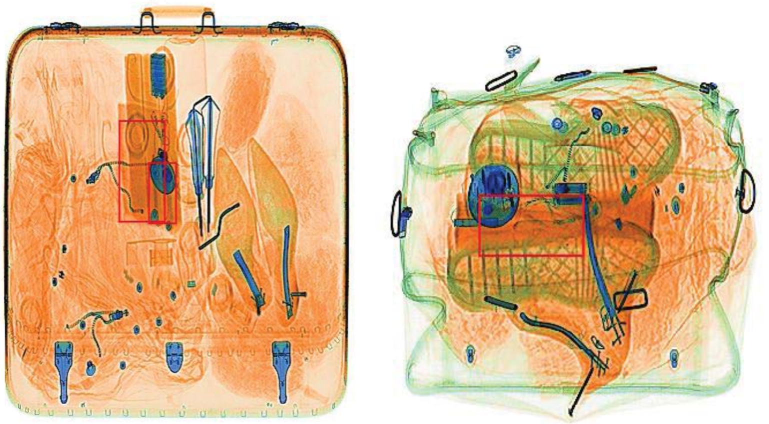

Fig. 2. Sample scanner image containing explosive artifacts composed of dynamite with a 9 volt battery (left) and TNT with AAA batteries (right). Both images belong to the “explosive” or “positive” class.

Images are colored, by many x-ray luggage scanners (including the ones used in this work), as follows:

- BLUE: "Hard" materials; Metals (also in BLACK), hard plastics, alloys; firearms, knives, cables, batteries, etc.
- ORANGE: Biological material mainly; Not exclusively natural; Leather, food, dynamite and other explosives (not plastic ones); Liquids, gels, organic powders, etc.
- GREEN: Alloys of lower density; Also ceramics; Not organic; Combined with BLUE in electronic devices.

2.3 GDXray - GRIMA database - firearms data-set

From [4], as a service to the X-ray testing and Computer Vision communities, Domingo Mery and his team collected more than 19.400 X-ray images for the development, testing and evaluation of image analysis and computer vision algorithms. The images are organized in this public database called GDXray: The GRIMA X-ray database (GRIMA is the name of a Machine Intelligence Group at the Department of Computer Science of the Pontificia Universidad Catolica de Chile). The X-ray images included in GDXray can be used free of charge, for research and educational purposes only.

The quantities per class, in two reduced data-sets made up for this particular project, to test the detection of firearms and of knives, separately, are shown in table 2 and table 3. Dataset was partitioned by the authors; all images from the original dataset were used and the final labeling of each class can be obtained from the github repository.

Table 2. Firearms GDXray data-set quantities per class.

Firearms	1117
General luggage (negative)	8445

Table 3. Knives GDXray data-set quantities per class.

Knives	2246
General luggage (negative)	7321

Fig. 3. X-ray sample images of firearms and general luggage from the GDXray GRIMA database.

3 Results of first experiments

According to common practice in training and evaluating machine learning models, and also following the default method in TensorFlow library, data-sets were divided into three subsets: a training subset comprising 80% of the complete, original data-set; one for validation, containing 10% of the samples -also used during the training-; and a last subset, for the final testing, containing the remaining 10% of the data-set images, which are left aside until this final, one time evaluation.

It is also worth noting that the results are represented in approximate ranges given that various training and data augmentation experiments have been performed, besides that in each case, there are variables that are initialized with random values.

3.1 Results obtained for the PSA images data-set

Using the PSA images data-set, we have evaluated the training, validation and testing, with three classes (explosives, firearms, and negative); With the main objective of recognizing explosive devices. Results are shown in table 4, considering explosive artifacts exclusively.

Table 4. Results for the PSA data-set.

Results for training subset	95 – 100 %
Results for validation subset	89 – 98 %
Results for testing subset	84 – 90 %

3.2 Results obtained for the GDXray GRIMA data-set

For the two GDXray GRIMA based sub data-sets (of firearms and knives), the results of training, validation and testing phases are summarized in tables 5 and 6.

Table 5. Results for the GDXray GRIMA firearms sub data-set.

Results for training subset	98 – 100 %
Results for validation subset	95 – 99 %
Results for testing subset	92 – 98 %

Table 6. Results for the GDXray GRIMA knives sub data-set.

Results for training subset	97 – 100 %
Results for validation subset	95 – 98 %
Results for testing subset	90 – 97 %

4 Open source project – RIS

The project was named RIS (for *Reconocimiento de Imáges de Scanners* in spanish, or Scanners Image Recognition). General instructions and source code of the web-service and auxiliary scripts developed for the evaluations will be published on github at https://github.com/dgt-psa/ris. Information regarding the web-service for the classification of images of x-ray scanners can be found in the project README.md, including obtaining estimates from generated models, installing TensorFlow on Linux, installing the rest of the web service dependencies, the generation of new models, re-training the last layer of the Google inception model, etc.

The tests have been performed on Ubuntu server 14.04, with Python 2.7 and the installation of required software was done accordingly to what is described in https://www.tensorflow.org/install/install_linux#InstallingVirtualenv.

The project was first presented in ANDSEC security conference, when source code was made available in DGT's github repository.

This software can be redistributed and/or modified under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or any later version.

5 Future work

Planed future work includes continuing the compilation of relevant information from academic, government (other countries) and private experiences; and the evaluation of other free software libraries that enable the implementation of machine learning for image recognition.

Besides the implementation and operation of the online analysis of images for alerting in support or as a "second opinion" for the scanner operator, and regarding research specific tasks, the list includes:

- Acquisition of more x-ray images (positives and negatives) from PSA scanners.
- Evaluate other sets of images for training, validation and testing (from researchers, universities, other security or police institutions, etc.)
- Evaluate training and evaluation with different types of machine learning classifiers.
- Confirm technical feasibility and threshold or acceptable range of precision.
- Getting help from potential collaborators: contributions from the manufacturers and/or distributors of x-ray luggage scanners and/or other third parties.
- Train with dedicated hardware, considering the important performance difference in equipment with, for example, special video cards.
- Consider the use of the same technology for other applications, for example, the recognition of clandestine airstrips.

6 Conclusions

This research and development project, currently in progress, aims to confirm that available free and open source software could be used for image recognition to alert the operator (or screener) of x-ray luggage scanners about images identified as threats (explosive devices, firearms, knifes, etc.)

Although we need to continue experimenting with different alternatives with regarding to software, pre-trained models, and image-sets, to confirm if the accuracy or threshold of acceptance of the classifications, we consider the results obtained in this first stage of the project encouraging.

Sharing on github the experiments that were carried out, the tools and the methodology used, we hope that interested third parties can reproduce the work described in this paper and eventually collaborate openly on the project.

7 Acknowledgements

The organic and functional structure of the PSA (Airport Police Security, or *Policía de Seguridad Aeroportuaria*) is integrated by a civilian management and administration structure, an operational police structure, and the higher institute of airport security. The DGT (Technological Management Department, or *Dirección de Gestión Tecnológica*) is responsible for managing, developing, providing and controlling the administrative, technological and communication support goods and services for data processing and access to information, as well as researching and implementing state-of-the-art technologies that ensure availability, integrity and reliability of information. (Ministry of Security Resolution # 1015/12).

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