REPORT ON COMMERCIAL AI SYSTEMS (UPDATE AUGUST 2023)

TRAI: Target Recognition Using Artificial Intelligence
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1. CONFIDENTIALITY

This report including its attachment does not contain any confidential information and is not restricted to any particular audience. The publication of information that is not publicly available has been approved by the surveyed providers of APIDS (Automated Prohibited Items Detection Systems). Therefore, this report can be shared with airports or other interested organisations.

This report is based on a report that includes additional, restricted information, discusses some additional aspects relevant for the certification of APIDS, and is only available to members of the TRAI project and regulators.

2. AUTHORS AND CONTRIBUTORS

This report was written by the Center for Adaptive Security Research and Applications (CASRA) with the highly appreciated support of the surveyed APIDS providers. CASRA is a leading organization for research and applications to strengthen security. CASRA's portfolio includes publications, research projects and software products for airports. This report is part of a comprehensive research project that investigates the potential of AI systems for detecting prohibited items in X-ray or CT images of passenger baggage (often referred to as Automated Prohibited Items Detection Systems, APIDS). The project is funded by the Swiss Federal Office of Civil Aviation (FOCA) and will provide recommendations and guidance to airports and regulators in Switzerland and the European Union.

3. INTRODUCTION

3.1. THEORETICAL BACKGROUND

X-ray security screening at airports is widely used for maintaining aviation security. To ensure passenger security, carry-on luggage, and personal belongings, among other items, are screened for potential threats (Petrozziello & Jordanov, 2019). Human operators (screeners) then decide whether prohibited or dangerous items are present in such an image. However, several factors can negatively affect detection performance of human operators at checkpoints (see for example Akcay & Breckon, 2021). Hence, there are ongoing technological advances for a more effective and efficient checkpoint. Unlike humans, artificial intelligence (AI) does not fatigue or succumb to volatile errors due to distraction, which is why constant performance is ensured (Hecker & Paass, 2020).

AI is already in use for *Explosives Detection Systems* (EDS), where item recognition is based on materials. However, recently, there have been further additions that make use of deep learning AI systems to detect prohibited items also based on shape (Wang et al., 2020) – so called *Automated Prohibited Item Detection Systems* (*APIDS*). Based on comparison with the data known to the AI, the system can detect prohibited or dangerous objects.

Since APIDS are a relatively new technological advancement, opportunities and risks are yet to be researched. By now, a first common evaluation process has been adopted for the certification of APIDS in the UK and the EU. But APIDS certification is still in an early phase and recommendations for specific systems and their implementation is still scarce.

3.2. PURPOSE AND HISTORY OF THE REPORT

The purpose of this report is to summarize and describe the systematic analysis of commercially available APIDS. The analysis was carried out as part of the Project "TRAI – *Target Recognition using Artificial Intelligence*". A first investigation was already carried out in the second half of 2021. The investigation began with an online research and document analysis with the aim to familiarize with the topic of APIDS and the procurement of an overview of various providers and systems. To this end, information on available APIDS and their application was collected from public sources. The information that was available online turned out to be somewhat superficial. Hence, many questions and aspects remained unanswered. Therefore, the APIDS providers were contacted via email. They were informed about the TRAI project and were asked to participate in a survey about APIDS. After having received their written answers to the questionnaire, semi-structured interviews were conducted. During these virtual meetings remaining questions and aspects were clarified.

The first research of commercially available APIDS in 2021 located eleven APIDS providers. Eight providers participated in the survey. Based on the findings from the survey (questionnaire and interviews), a first report about APIDS was written and published at the beginning of 2022. The report was provided to the FOCA, all Swiss airports, as well as serval European airports and regulators.

Due to the rapid development of APIDS, further research was conducted in 2023 with the aim to update the report. On the one hand, the aim was to find out possible updates from the manufacturers who had already participated in the first round in 2021. On the other hand, possible other APIDS providers should be found that were not yet included in the first report.

3.3. OBJECTIVES

An implementation of APIDS at airports can bring several potential advantages, but also raises various questions that need to be addressed. The TRAI project aims at answering these questions, mainly for airports and regulators in Switzerland, but the insights are expected to be valid beyond. Hence, this project investigates how APIDS can be used to increase the effectiveness and efficiency of security controls at airports to prevent security risks.

The report on commercial AI systems from January 31st, 2022, provided an overview of the currently available APIDS, their similarities, differences, and the applications they promise. Because APIDS are rapidly evolving and new providers have entered the market, the report was updated in the first half-year 2023.

3.4. TERMINOLOGY AND CONCEPTS

In the following, the concept of APIDS is described in the context of AI in a little more detail and the most important terminologies for it are introduced (see Figure 1). AI is "*any technique that enables computers to mimic human behaviour or reproduce or excel over human decision-making to solve complex tasks*" (for a review see Janiesch et al., 2021). AI therefore concerns itself with knowledge representation, reasoning, learning, planning, perception, and communication. One major subfield of AI is machine learning (ML) where algorithms can improve their performance through data with experience over time. ML is mainly divided into supervised, unsupervised, and reinforcement learning. Deep learning (DL) is a subfield of machine learning that involves deep (artificial) neural networks with many layers of processing units and can therefore outperform other ML algorithms for most applications for image processing (given that there is enough training data available). APIDS are DL applications used within X-ray security imaging. More detailed information about terminologies and concepts will be given in the report on the current state of relevant AI research ("*Technologieanalyse zum aktuellen Forschungsstand zu KI-Systemen*").

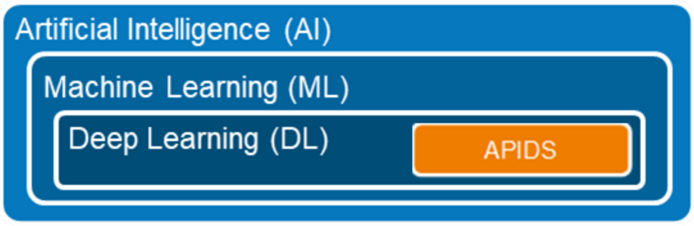

Figure 1: APIDS as a specific application of deep learning.

4. PROCEDURE AND METHOD

4.1. ONLINE RESERACH

The providers who were involved in the first survey and report were contacted again. Furthermore, there may be providers who either had no online presence by the end of 2021 or were not found in our first search, which is why a new online search was conducted in 2023. The following keywords were used for the online research (partly stand alone, partly in combination, in alphabetical order):

- Airport security screening
- APIDS
- Artificial Intelligence
- Automated prohibited item detection system
- Automated threat detection
- Cabin baggage
- Carry-on baggage
- Hand luggage
- Object detection
- Threat detection

4.2. SURVEY

In a first step, the questionnaire was revised by rephrasing old questions to make them more clear and adding some new questions based on the experiences gained in the first survey and from previous studies and investigations. In addition, questions that had turned out to be of little use in the first survey were eliminated (e.g., the question about the product price, which none of the suppliers could or wanted to provide). The aim of the updated questionnaire was, on the one hand, to give the providers the chance to update their answers, and, on the other hand, to expand the overview of commercially available APIDS providers and present them.

In total, 16 providers were contacted via email. Aurora Computer Services and Daifuku Airport Technologies were contacted but did not participate. Providers that were involved in the first survey received the updated questionnaire with their answers as they were summarized in the first report to facilitate updating them. Out of the eight providers that were included in the previous report, five provided updated information on their product. One company informed us that they were no longer pursuing the development of APIDS. Two companies did not provide any updates.

Four new APIDS providers were identified and contacted via email for a short virtual meeting to introduce the project and the report: Auxilia, Krystalvision, Nuctech Company Limited and Pangiam. Krystalvision did not participate while Auxilia, Pangiam and Nuctech did.

After receiving the written answers from the questionnaire, the providers were contacted to clarify open aspects and questions where necessary. The answers to the questionnaire were analysed categorically and are presented in the next chapter.

5. RESULTS

5.1. SURVEY

The results of the systematic analysis of the answers to the questionnaire are presented below. First, an overview of all APIDS providers who are included in this year's survey is provided. The following paragraphs then summarize information across all providers per topic and highlight similarities and differences between them.

This report includes the following ten companies who provide APIDS that can be deployed at airport security checkpoints (in alphabetical order):

- Auxilia
- Dimensionless Technologies
- IDSS – Integrated Defense and Security Solutions
- Leidos
- Neural Guard
- NUCTECH Company Limited
- Pangiam
- Rapiscan[1]
- SeeTrue Screening
- Smiths Detection

For Rapiscan and Smiths Detection, the reported information on their APIDS is based on the first report because they did not provide any updates.

Table 1 in the appendix shows more detailed information from each provider. This detailed information is helpful for a more in-depth examination of the topic but not necessary for the understanding and the core statements of this report.

5.2. COMPOSITION AND COMPATIBILITY

Most providers offer systems that can be used with 2D X-ray single-view as well as multi-view and also provide systems for 3D scanners. Three providers each offer an APIDS tuned to a certain model of 3D scanner.

[1] For 3D CT machines, Rapiscan cooperates with the company Analogic, therefore their provided information regarding 3D CT includes Analogic.

To discuss the compatibility of APIDS with specific machine types, the different options to install or connect APIDS should first be understood. Depending on the APIDS provider and the machine model, APIDS run directly on the machine, on a separate machine, or providers even offer both solutions. The APIDS from Neural Guard, SeeTrue, and Pangiam can also run on servers for centralised image processing (CIP) while Neural Guard also has a cloud solution. An APIDS for 2D X-ray that runs on a separate machine is typically interposed between the X-ray machine and the monitor (i.e., connected via VGA, DVI, HDMI or display port).

Concerning the machine model compatibility, most APIDS are compatible with several X-ray / CT machines from leading manufacturers like Astrophysics, IDSS, Leidos, Nuctech, Rapiscan, or Smiths Detection. Some APIDS have only been tested on certain machine models but can be tuned to other machine models as well. Due to direct integration, some APIDS are solely compatible with specific machine models. In general, APIDS from machine manufacturers are currently only available for their own brands. Nuctech offers both a built-in APIDS for their own machine models and APIDS on separate machines for X-ray machines of other manufacturers.

5.3. FUNCTIONALITY AND PERFORMANCE

Essentially all APIDS can detect guns, knives, and other sharp objects. Most providers also explicitly pointed out that they can detect parts of guns like magazines and ammunition, or tools as well. Furthermore, some APIDS can detect objects such as (e-)cigarettes, power banks, hand grenades or large electronics. Table 1 in the appendix shows more detailed information. Detecting a prohibited item takes usually between under one or a few seconds. For CT scanners, the detection time is slightly higher than for X-ray machines.

Usually, when the APIDS detect a possible threat, a coloured bounding box marks the prohibited item on the operator's screen. For 3D images, in some cases, an optional voxel overlay can be turned on or off. Also, additional sound alerts or other notifications can be available. In most cases, the threat category (knife, gun, etc.) is available in the offline report but is not shown by default in operation. But most APIDS have the option to show the threat category, either by annotating the frame or by using different colours for frames and providing a legend that informs about the meaning of the colours. Some APIDS even allow customizing the level of detail of the detected threat category. However, it should be considered that classification errors will inevitably become more frequent when a detailed threat categorization is displayed. Information about of the APIDS's confidence is usually available. Few APIDS providers show the confidence score by default whereas most providers do not.

To get a better understanding of the current performance of APIDS, we asked providers about the detection rate and false alarm rate of their APIDS. Some providers did not disclose any information on this. For those who did, it can be summarized that the reported detection rates are above 80% and often above 90% for almost all item categories, whereby the detection rate for guns is slightly higher than that for knives. It should be noted that the reported detection rates are not derived from a fixed and comparable set of prohibited items and therefore are not comparable but should only be considered as a rough estimate of current detection capabilities. False alarms, which means that the APIDS wrongly marks a harmless item, vary from almost 0% up to 10%. On average, the reported false alarm rates are below 5%. It is generally expected that the false alarm rate will continue to decrease with the ongoing development of APIDS.

As with human screeners, how well APIDS detect threats depends not only on the threat itself (e.g. density and size), but can also depend on various characteristics of the X-ray image. It was mentioned repeatedly by providers that strong superposition can reduce detection and also many prohibited items are detected worse in certain orientations. APIDS running on dual-view machines are less prone to misses due to orientation or superposition, as there is a good chance that a high superposition or difficult orientation in one view is less of an issue in other views.

Orientation and superposition are even less of an issue in 3D CT images, which, on the other hand, have to rely on lower spatial resolution. When discussing the effect of superposition on detection, it is also worth noting that many of the APIDS have built-in capability to detect high density areas (shielding / dark alarm) beyond the usual detection provided by the X-ray machines. It is also worth noting that APIDS might likely require less contrast of the prohibited item compared to human screeners for detection. Because of the above-mentioned dark alarms, dense and heavy objects are prone to causing rejects despite the absence of a threat item. Further, objects that look similar to prohibited items can cause false alarms, e.g. long and pointy objects such as metallic bag supports, can be mistaken for knives and thus lead to false alarms. As explained above, 2D multi-view and 3D CT have an advantage over 2D single-view in detecting prohibited items that are strongly superimposed or in a difficult orientation in the main view.

5.4. TRAINING

As most providers state, hundreds if not thousands of images are required to train an APIDS to recognise a certain type or category of prohibited items. The number of images depends on the complexity and variety of those items and on the similarity of those prohibited items to non-threat items. Accordingly, capturing images of baggage with real threat items is a time-consuming and correspondingly costly endeavour, which could be mitigated through the use of synthetic images. In this report, we use the term *synthetic* to describe images that were created by merging images of threat items into separately recorded images of harmless baggage. Some of the providers have developed an algorithm to create synthetic images. Some providers trained their algorithms exclusively with real X-ray images, others did this as well with synthetic images. However, most of them can imagine using synthetic data in the future.

5.5. IMPLEMENTATION

To provide a better understanding of the implementation process of the APIDS, we wanted to know from the providers which steps are required to install the APIDS at an airport. This question was very open-ended, which is why the answers varied across several topics.

Further, we asked the providers whether the APIDS need to be calibrated after installing the software respectively after connecting the separate device to the scanner. Most of them stated that beyond the usual calibrations of the X-ray or CT machines, no calibration specific to the APIDS is needed, while others apply some minor adjustments. This implies that APIDS are robust to variations within and between machines of the same model as long as they do not fall below a certain threshold of the signal-to-noise ratio, which is typically monitored by the machine.

Finally, we asked the providers if they plan to conduct an on-site acceptance test to ensure that the APIDS performs as intended. Some providers are confident that their APIDS runs as intended after implementation and do not perform specific tests for verification. Some companies perform an on-site acceptance test with various prohibited items and bags to ensure proper functioning of the system.

By EU regulation, airports will have to make sure that all screened baggage meets the requirements (e.g., no large electronics or liquids for EDS C1) of their explosives detection system if they want their APIDS to clear a share of the baggage without human intervention. We therefore asked the APIDS providers whether they offer or plan to offer a solution to help airports meet these requirements. Because CT machines running EDS-CB standard C3 do not require divesting large electronics or liquids, they do not require such a solution. The software from Dimensionless Technologies can detect large electronics anyway. Other providers mentioned that they already have a solution or are planning one.

5.6. TESTING, INTERFACES AND ARCHITECTURE

If the current approach to regulatory testing and certification is followed, APIDS will have to be certified for each machine type separately and will have to be recertified if changed. It will therefore be an advantage if not each of these tests has to be conducted with real bags and threats, but rather pre-recorded images can be used. For a better understanding of what such testing might look like, the survey included some questions on the availability of emulators and on the input and output of the APIDS and their emulators. Emulators will also be beneficial for human factors studies, and likely for future training of screeners who will work collaboratively with APIDS.

Suggestions from providers about the preferred input interface depends on the type of scanner. For 2D scanners, RBG images with pseudo-colour material discrimination in a non-compressed or lossless image format are suggested by the third-party APIDS providers. One machine manufacturer would want their APIDS tested with their proprietary image format. For 3D CT devices, DICOS (Digital Imaging and Communication for Security) is primarily proposed as an interface.

Because different X-ray machines provide different image resolutions and even for the same type of X-ray machine the width of one image depends length the baggage occupies on the belt, most APIDS can cope with different input resolutions. For some APIDS it was mentioned that they apply pre-processing to the image input like cropping or scaling. Other pre-processing techniques used by providers besides size normalisation include conversion to grey scale, thresholding and edge preserving smoothing. Many providers see their pre-processing as a business secret and did not provide any information.

To get a better idea of how APIDS can be tested, we asked providers about their approach to testing. The question of how the manufacturers determined the detection and false alarm rates of their APIDS was very open and the answers were therefore no less informative. Some of the companies who were willing to provide information stated that they have determined the rates with thousands of images of real baggage or a combination of real and synthetic images containing prohibited items. Almost all providers have already developed an emulator and tested their APIDS both with the emulator and on the scanner to determine their detection and false alarm rates. One provider only tested on scanners.

To better connect the commercially available APIDS to current research on APIDS, we also asked a few questions on the architecture of the algorithms used by the different providers, which revealed that APIDS are usually based on Deep Learning and Convolutional Neural Networks (CNN) but did not provide much more detail because providers understandably guard such information as a business secret.

We asked anew whether the APIDS manufacturers already offer or plan products that are based on anomaly detection and not on object detection. Some stated that they are not yet doing this, others did not want to comment on this, and few providers stated that they already provided solutions for anomaly detection.

5.7. BUSINESS SEGMENT

All providers believe that their APIDS is not only suitable for CBS or in the context of airport security but can also be extended to other industries and areas. Most companies have already tested their APIDS at an airport, are in the middle of a trial, or are planning one. A few companies have already put their system into permanent operation at an airport. We wanted to know from the providers whose APIDS is already in use how APIDS alarms are handled. Most indicated that alarm resolution is either done on screen (operator assist) or the alarms are resolved at the recheck station.

Machine learning algorithms can be set up to receive feedback and update during operation. This allows the algorithm to adjust in real time to a changing situation. In the context of APIDS, however, this approach would pose problems. The APIDS might eventually learn that not alarming is the lowest cost response, as the vast majority of scanned baggage does not contain any prohibited items. Live adaptation of an APIDS would require continuous monitoring so that the required detection rates are met and would complicate the certification process. All providers therefore currently foresee that their APIDS will not adapt in operation, some of them referring to the aforementioned issues. However, most providers stated that they use the feedback from the field and make corresponding improvements and provide updates after completing any necessary recertification.

6. DISCUSSION

The aim of this report was to provide an updated overview of the currently available APIDS and to describe and discuss similarities, differences, and possible applications. The report is intended to inform Swiss airports and authorities about currently available APIDS and their implementation, and to serve as a contribution in the decision-making process for the optimal use of APIDS.

6.1. LIMITATIONS

As already the case for the first survey in 2021, we again found that providers varied regarding the scope and level of detail of their statements. Understandably, providers want to keep certain information confidential. Deriving generally valid statements as well as a comparison between the providers was therefore difficult in some cases.

6.2. REMAINING QUESTIONS

Whereas the two surveys provided information on many relevant topics, several important questions are still unclear.

Some providers have trained their APIDS using only real data, whereas others have used both real and synthetic data. However, from the disclosed information, it remains still unclear whether APIDS should be trained exclusively with X-ray images or whether synthetic images could also be used. Access to images of baggage without threat items is much easier, as countless such images are produced every day. Therefore, the generation of synthetic data is only interesting for images of baggage with threat items. However, such synthetic data may contain artefacts created by the merging process. Consequently, training APIDS with synthetic data could cause them to learn to detect artefacts instead of threat items. On the other hand, the use of synthetic data would have the advantage that many images can be created rapidly and at relatively low cost. Future research must finally show whether synthetic images are capable of training APIDS to achieve a high detection rate.

With a first certification process established in 2023, standardized performance evaluation of APIDS has significantly progressed since our first report on commercial APIDS. But, to our knowledge, no open image standards or interfaces have been finalized yet that would allow third party providers direct access to certification based on pre-recorded images. Because providers use different approaches, establishing a such image standards and interfaces is a challenge, but one that would be important in the long term for an efficient and cost-effective certification process.

7. CONCLUSION

As already in the first round of the survey in 2021, the providers were very helpful in providing information about their APIDS and showed great interest in the project and its further developments. The update of the report has proven to be useful in several ways. It could be extended by three new APIDS providers. Furthermore, there were relevant updates from the previous participants. Ultimately, a few questions were added to the second survey in 2023.

The provided information suggests that a APIDS have by now be deployed permanently at a few selected airports. A variety of APIDS are or soon will be ready to be deployed more widely. The APIDS covered in this report have the potential to increase both security and efficiency of airport security in Switzerland. However, there are still several open questions, e.g., regarding CONOPS, operational testing, and open standards (standardized image formats and interfaces) for APIDS.

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9. LIST OF FIGURES

10. LIST OF TABLES

11. APPENDIX

Table 1: Answers from providers to interview questions

N/A: Information missing, not applicable to the APIDS in question or declared as confidential.

	Auxilia	Dimension-less Technolo-gies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
COMPOSITION AND COMPATIBILITY										
System compatibility	› 2D X-ray single-view › 2D X-ray multi-view › 3D CT › Note: it is best suited for 2D scanners (single or multi) as it does not benefit from 3D scans	› N/A	› 3D CT	› 3D CT	› 2D X-ray single-view › 2D X-ray multi-view › 3D CT	› 2D X-ray single-view › 2D X-ray multi-view › 3D CT	› 3D CT	› 2D X-ray single-view › 2D X-ray multi-view › 3D CT	› 2D X-ray single-view › 2D X-ray multi-view › 3D CT	› 2D X-ray single-view › 2D X-ray multi-view › 3D CT
Hardware on which the system is running	› On a separate machine	› N/A	› Directly on the CT machine	› Directly on the CT machine	› On a separate machine (add-on computer) › Local CIP server	› Directly on X-ray and CT machine › plug and use device	› On a separate machine (size of small computer tower)	› Directly on the X-ray or CT machine	› On a separate machine › Directly on the X-ray or CT machine	› On a separate machine for X-ray › Directly on the CT machine

	Auxilia	Dimension-less Technolo-gies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
					› Cloud server	for X-ray machine	› Local CIP server		› Local CIP server	
Connection to the machine when not running directly on the machine	› via HDMI / VGA	› N/A	› N/A	› N/A	› Via VGA / DVI/ DisplayPort/ HDMI	› LAN connection	› LAN connection	› N/A	› N/A	› N/A
Machine model compatibility	› Any brand	› N/A	› IDSS: DETECT™ 1000	› Leidos: ClearScan	› N/A	› built-in APIDS system compatible with all Nuctech X-ray/CT series product. › Plug-and-use APIDS system compatible for other X-Ray machines	› IDSS (now), Smiths Detection (July 2023), Analogic (August 2023), Leidos (planned) › All machines that will provide images in Dicos or provide point cloud data	› Rapiscan: 620DV, 920DX, 920CT	› N/A	› Smiths: 2D X-ray and 3D CT scanners
FUNCTIONALITY AND PERFORMANCE										

	Auxilia	Dimension-less Technolo-gies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
Types of prohibited items detected	› N/A	› handguns made of metal or containing metal parts › handguns made of plastic or 3d-printed › rifles › handgun parts/com-ponents › rifle parts/comp onents › knives with metallic blades › knives with organic blades › foldable knives › sharps weapons › tools (e.g., scissors, screwdriver scalpel, box cutter)	› handguns made of metal or containing metal parts › handguns made of plastic or 3d-printed › rifles › handgun parts/com-ponents › rifle parts/com-ponents › knives with metallic blades › knives with organic blades › foldable knives › sharps weapons › tools (e.g., scissors, screwdriver scalpel, box cutter)	› handguns made of metal or containing metal parts › handguns made of plastic or 3d-printed › rifles › handgun parts/com-ponents › rifle parts/com-ponents › knives with metallic blades › knives with organic blades › foldable knives › sharps weapons › tools (e.g., scissors, screwdriver scalpel, box cutter)	› N/A	› handguns made of metal or containing metal parts › handguns made of plastic or 3d-printed › rifles › handgun parts/com-ponents › rifle parts/com-ponents › knives with metallic blades › knives with organic blades › foldable knives › sharps weapons › tools (e.g., scissors, screwdriver scalpel, box cutter)	› handguns made of metal or containing metal parts › handguns made of plastic or 3d-printed › rifles › handgun parts/com-ponents › rifle parts/com-ponents › knives with metallic blades › knives with organic blades › foldable knives › sharps weapons › tools (e.g., scissors, screwdriver scalpel, box cutter)	› Guns › Sharps (e.g. knives, scissors) › Blunt objects, › Grenades › Liquids › Laptops	› handguns made of metal or containing metal parts › handguns made of plastic or 3d-printed › rifles › handgun parts/com-ponents › rifle parts/com-ponents › knives with metallic blades › knives with organic blades › foldable knives › sharps weapons › tools (e.g., scissors, screwdriver scalpel, box cutter)	› Guns › Knives › Blunt objects › Grenades › etc.

	Auxilia	Dimension-less Technolo-gies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
		› ammunition › others: E-Cigarettes, Power-bank, Cigarette Lighter	› ammunition › others: Hand Grenades, hammers, hatchets, wrenches	› ammunition		› ammunition › others: grenade, detonator, fireworks, blunt object (hammers, batons), electro-shock weapons, pepper sprays, liquid bottles, knuckles, electronics (e.g. laptops, tablets, phones), power banks, bottles, com-pressed air tank, slingshot, crossbow, swords, axes, etc.	› Grenades › Detonators › Next generation threats and other items of interest		› ammunition › others: Grenades, Blasting Caps	

	Auxilia	Dimension-less Technolo-gies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
Detection time	› 0.2 s	› 0.5 s	› N/A	› A few seconds	› About 0.1 s	› Image displays with APIDS results instantly, no additional waiting time	› Few seconds	› X-ray: 1-2 s › CT: less than 5 s	› Under 0.5 s	› Does not cause any additional processing time
Display of alarms	› A bounding box marks the prohibited item › Boxes are drawn in red for every detection class by default but can be changed in a setting panel › The confidence score is not displayed by default, but this can	› A bounding box marks the prohibited items with different colours. › Accompanied by a sound alert › A legend indicates the meaning of the colours. › The confidence score about the APIDS' decision is displayed	› A red bounding box marks the prohibited item. › Optional voxel overlay that can be turned off by the operator	› Prohibited items are indicated by a bounding box and/or pixel shading in the image of the identified potential threat. The threat indicator can be toggled on/off to aid in inspection via the button	› A red bounding box marks the prohibited item. › The entire screen frame is marked with a red square and "Alert" appears in red. › External voice and visual notification options are also available	› On screen alarm box › optional confidence score and alarm category display	› Bounding box on all user interfaces › Object separation on Pangiam user interface › Segmen-tation will be added in the future › Whether showing the confidence score is useful, will be investi-	› A bounding box marks the prohibited item. › Optional voxel overlay for 3D CT with different colours, indicating different threat categories	› A red bounding box marks the prohibited item. › Accompanied by an optional sound alert › Optional annotation of the threat category	› A bounding box marks the prohibited item

	Auxilia	Dimension-less Technolo-gies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
	be changed in a settings panel	when alarming		labelled “Prohibited” displayed on the bottom left-hand side of the screen	› The confidence score about the APIDS’ decision is normally not displayed when alarming, but can be made available to the client upon request		gated in human-factors-studies			
Detection rates	› N/A	› N/A	› N/A	› N/A	› N/A	› 85%-98% for all objects	› N/A	› Guns: ≥ 90% › Knives: ≥ 80% › Blunt objects: ≥ 90% › Grenades ≥ 85%	› N/A	› High and at least comparable to human operators
False alarm rates	› N/A	› N/A	› N/A	› N/A	› N/A	› Less than 5% for all objects	› N/A	› Less than 10% for all objects	› N/A	› Less than 10% for all objects
Character-istics of the image or prohibited	› None	› In merged images, ratio of	› N/A	› N/A	› Generally lower	› Rotation especially	› N/A	› Density and size	› None	› None

	Auxilia	Dimensionless Technologies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
items that are relevant for their detection		threat image and baggage image			detection in side-view	for 2D systems › Material affects both 2D and 3D systems		› Guns are detected based on specific features such as the steel barrel		
Attributes/ distractors that make detection more difficult	› Orientation (for example front-facing bullets are very hard to detect)	› Orientation	› N/A	› N/A	› Angles › Many objects placed together › Dense distractors › Contains electronics	› Overlapping objects › Specific orientations or postures in conventional X-ray scanner	› N/A	› Small blades in difficult orientations in X-ray images	› None	› Under investigation
Other systematic patterns in mis-classified images, characteristics of non-prohibited items that cause false alarms or specific non-prohibited items that	› Metal pen or e-cigarettes can sometimes raise alarms for sharp objects as they might look like folded knives › Heavy zippers can	› Mobile phones have been mis-classified as power banks › Screws of the trolley bags and zips have been mis-classified as plastic disposable	› During development, certain systemic patterns were noticed, and corrections were made to the training approach to address	› N/A	› Systematic patterns in misclassified images: Depending on the item category › No specific non-prohibited items that cause false alarms	› When the image or physical characteristics of non-prohibited and prohibited products are close, the possibility of being falsely alarmed	› N/A	› Some threats such as small - bladed weapons can be significantly more difficult to detect than others (such as guns).	› N/A	› Similar densities or shapes

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cause false alarms	also be mistaken for ammunition	cigarette lighters	› No specific non-prohibited items that cause false alarms			will be increased. For example, a flat sheet of metal has the potential to falsely alarm as a knife		› Flat metal items can be confused for knives		
System for which APIDS show the best performance	› 2D single-view	› 2D dual-view provides better detection performance than 2D single-view	› N/A	› N/A	› N/A	› More views (especially 3D can be regarded as an infinite number of views) can provide more imaging angles for items and overcome the difficulty of recognition caused by object overlapping	› N/A	› CT is expected to ultimately significantly outperform 2D.	› 3D and 2D dual-view provides better detection perfor-mance than 2D single-view	› Under investigation

	Auxilia	Dimension-less Technolo-gies	IDSS	Leidos	Neural Guard	Nuctech	Pangiam	Rapiscan	SeeTrue	Smiths Detection
						or different orientation.				
TRAINING										
Training of algorithms: real recordings, synthetic images, or both	› Both	› Both	› N/A	› N/A	› Real X-ray recordings on a variety of machines (over 10 million prohibited items) combined with advanced capabilities and various AI methods. Synthetic mani-pulations are performed on these images to increase the algorithm robustness.	› N/A	› Only real recordings › Using synthetic images is not expected at this stage	› Synthetic images are beneficial for 2D, less for 3D	› Only real recordings	› Only real recordings › Using synthetic images is under investi-gation.
Number of images needed to train novel items	› A few hundreds of images of different	› 2000 images › Depending on	› N/A	› N/A	› Tens of thousands of images	› N/A	› N/A	› Ideally hundreds to	› Relatively low number of images compared	› Hundreds to thousands of images

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	instances of the object, in different poses	complexity and variety			› Depending on complexity and variety			thousands of images	to industry standard › Unique technology	
IMPLEMENTATION										
Steps required in order to install the APIDS at an airport	› Usually, we propose a demo to the airport to show off our solution live, and then propose a 6-month trial period. Our solution is plug and play and only requires power supply	› Identifying the X-ray machine output type › Setup of Solution workstation › Calibration	› Once a detection algorithm is approved by the appropriate regulator, implement-tation consists of a simple software installation process on top of the normal DETECT software.	› Install APIDS algorithm on CT scanner and enable the feature	› In a simple procedure, the EyeFox system can be connected to an existing X-ray machine within minutes. It is possible to integrate automatic identification capabilities in a variety of ways, adapted to the needs of the customer and the regulatory authorities	› Additional software is required. Additional hardware might be required to install APIDS to existing system	› Easy installation in less than 20 minutes, requires power and network connectiv-ity	› N/A	› N/A	› N/A

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Calibrations required in order to run the APIDS	› No calibration specific to the APIDS › But in advance: Request for samples of images from deployed machines to confirm that Auxilia's solution is fitting and to fine-tune if necessary	› N/A	› No calibration specific to the APIDS	› Calibration is not required for APIDS	› N/A	› No additional calibration procedure	› None	› No calibration specific to the APIDS	› Scanning a test piece and a few scanned items, followed by a short adjustment, takes only some minutes	› No calibration specific to the APIDS
Types and duration of on-site acceptance testing	› These tests depend on the airport and are discussed during the 6-month trial proposal	› N/A	› Typically, site acceptance testing of a new, approved algorithm package is not required	› Not required	› A simple and quick acceptance test can be performed following the installation	› On-site acceptance testing procedure exists	› Running sample test bags through to ensure set up was successful. This should take around 30 minutes	› Not required	› Short on-site acceptance test using various prohibited items to ensure the system functions properly.	› Not required

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			› Further clarification: ATRs are tested internally at IDSS to ensure compliance with respective detection require-ments, which are then tested again by the regulator to ensure compliance.						They usually take a day or two	
Solution for verifying necessary divestment of large electronics (EDSCB C1 and C2) and liquids (C2)	› Is in planning	› We can detect large electronic like laptops and other items	› Not necessary (as 3D CT C3 allows laptops and liquids in bag)	› N/A	› N/A	› The capability is available and can be put to this application	› Not necessary (as 3D CT C3 allows laptops and liquids in bag) › Platform allows hosting	› N/A	› N/A	› N/A

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							third party algorithms which could take care of these require-ments			
BUSINESS SEGMENT										
Aviation areas where the APIDS can be useful	› CBS › Mail › Cargo › Customs › Etc.	› CBS › Customs	› Anything that can fit in a 60 cm x 40 cm tunnel	› CBS › Mail › Cargo › Customs › Staff screening	› CBS › Mail › Customs › Staff screening › Duty free products	› CBS › Mail › Cargo › Customs › Etc.	› CBS › Customs › Mail	› Primary focus for APIDS is for CBS	› All areas within aviation like CBS, HBS, border control, Mail, Customs, Cargo, etc.	› Any application subject to compliance with local perfor-mance and regulatory require-ment
Other industries where the APIDS can be useful	› Events › Prisons › Museums › Power plants › State buildings (police…)	› Metros › Govern-ment/ corporate offices › Stadiums › Malls › Schools › etc.	› Building protection › Border crossings › Critical infra-structure › etc.	› Border security › Mass Transit › Critical Infra-structure › etc.	› Law enforcement › Border control › Critical infra-structure › Cruise ships › Sports events	› N/A	› Customs	› Critical infra-structure such as govern-ment facilities, court-house, prisons	› Critical infra-structure › Public transporta-tion › Events › Stadiums › Schools › Customs	› Urban/ public spaces

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					› Family holiday parks › Mass transporta-tion			› Public places such as museum, sport centres and stadiums › Mail premises › Customs and border enforce-ment › Maritime, land and rail › etc.	› Correction-al facilities › Courts › etc.	
Airports deploying the APIDS	› Currently none but in discussion with some	› Bangalore Internat. Airport, India (operation-al trial) › Pune Internat. Airport, India (operation-al trial)	› Currently none in Europe › Has been tested at US Airports with the TSA	› N/A	› An operational trial of our system has already been conducted at over ten airports, and it is still ongoing at more airports.	› N/A	› Glasgow (as a trial) › Schiphol as a co-develop-ment partner › TSA trials › Heathrow and Melbourne to	› Currently none	› Deployed as operational trial at 8 airports › Deployed permanent-ly at 4 airports	› Currently none

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					Upon request, details will be provided to a potential client and/or the regulator		commence shortly			
How are APIDS alarms resolved at operational trials / permanent deploy-ments?	› N/A	› On-screen alarm resolution (operator assist) or alarms are resolved at recheck station	› N/A	› N/A	› Either on-screen alarm resolution (operator assist) or alarms are resolved at recheck station	› On-screen alarm resolution (operator assist)	› Currently shadow mode. On screen alarm resolution and alarms resolved at recheck station is planned for Q3 2023.	› N/A	› N/A	› N/A
Improve-ment based on operational feedback	› We offer our solution as a sub-scription. We provide updates based on our clients' feedback. With their agreement, we gather	› Yes. With periodic retraining and adjusting the thresholds	› We do not offer automatic algorithm updates. Algorithms are periodically updated based on field data, which then	› N/A	› Yes. Images are saved, and we use the information relevant to the customer to improve performance whenever he comments.	› Yes, the improve-ment is a continuous process	› Platform will run as a community-based model that improve using data from different airports and	› N/A	› Yes. We have feedback from the field and we upgrade either remotely or locally, in coordina-tion with	› N/A

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	images and improve our solution based on their problems		go into certification process by correspond ing authority (e.g., TSA or ECAC) before being deployed to the field		We offer this service in addition to our regular periodic improve-ment procedures		upgraded regularly		the regulators	
TESTING, INTERFACES AND ARCHITECTURE										
Input and output interfaces	› 2D: RGB	› 2D: RGB	› 3D: Hounsfield units	› N/A	› 2D: RGB › 3D: Depending on manu-facturer capabilities	› N/A	› DICOS › Point cloud data › Proprietary format with consent of OEM.	› 2D: attenuation and z-effective › 3D: Hounsfield units and Z effectives	› N/A	› N/A
Preferred input interface for certification of the APIDS with pre-recorded images	› Emulator providing the video signal	› RGB image with the pseudo colour material discrimina-tion	› DICOS	› N/A	› RGB images, captured the same way as done by the provider	› N/A	› N/A	› DICOS	› N/A	› N/A
Availability of emulators that allow	› Yes	› An emulator	› Yes	› N/A	› Tests on real	› N/A	› Yes	› Yes	› N/A	› N/A

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regulators to test it with pre-recorded images		could be provided in the future			machines are recommend-ed. › Tests with emulators are certainly possible, but it is important that the images will be real and not synthetic					
Allowed image resolutions as input into the APIDS	› Inputs are normalized and automatic-ally resized and padded to a fixed maximum dimension square	› All image resolutions are allowed, but it works best with the tunnel size up to 60/45cm. › The conveyer belt direction needs to be fixed	› The height and width are matched to the DETECT 1000. › The length is not specifically limited	› N/A	› The machine's video output is captured as a 1280x720 RGB image	› N/A	› Pre-processing is applied to normalize images	› The images sizes are typically constrained based on external factors such as TRS, BHS parameters rather than algorithmic limitations	› All image resolutions are allowed	› N/A

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Applied pre-processing techniques	› When APIDS is deployed: None › For algorithm training: Blurring, adding noise, hue rotation, resizes and affine transforms	› Size normalization and other processing techniques that highlight the unique features of the items	› N/A	› N/A	› N/A	› N/A	› N/A	› A range of corrections and normaliza-tion › Depending on the system	› N/A	› None
Deter-mination detection rate	› N/A	› N/A	› Use of 4000 images of bags containing prohibited items › Only real X-ray recordings	› N/A	› To determine detection and false alarms rate, the company uses a systematic metho-dology. Expertise and decades of field experience guide our research. As	› By specific sets of bags/ images	› In addition to internal testing, third party lab testing and third-party covert testing at trial lane was conducted	› X-ray: Combination of real and synthetic images containing prohibited items. › 3D CT: Only real X-ray recordings	› N/A	› N/A

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					a basis for our analysis, we used authentic prohibited items and data from the field. › We own a large real database of prohibited items with over 10 million images					
Deter-mination false alarm rate	› N/A	› N/A	› Use of 5000 images of benign bags › Only real X-ray recordings	› N/A	› See determinatio n detection rate	› By specific sets of bags/image s	› In addition to internal testing, third party lab testing and third-party covert testing at trial lane was conducted	› False alarm rates can be tested on stream of commerce bags which are easy to access.	› N/A	› N/A
Testing: Scanner or emulators	› On both	› On both	› On both	› On both	› Only on real scanners, for each	› On both	› On both	› On both	› On both	› On both

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					OEM and type separately					
Architecture	› Deep Learning based on CNN	› Deep Learning based on CNN along with some other image enhance-ment techniques	› Deep Learning based on CNN	› N/A	› Deep Learning based on CNN	› Deep Learning based on CNN	› Deep Learning based on CNN	› Mixture of determinis-tic learning and deep learning based on CNN	› Multiple AI and computer vision techno-logies	› Deep Learning based on CNN
Anomaly detection or other detection methods in addition to object detection	› No	› No	› N/A	› N/A	› N/A	› N/A	› Yes, the algorithm is specialized at detecting tampering with everyday objects (e.g. laptops) › Further: Our algorithms come with Aggregated Threat Detection (ATD),	› N/A	› N/A	› N/A

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							which will help detect coordina-ted threats spread across bags, lanes and checkpoints - for example dis-assembled weapons through pattern analysis and rules-based targeting			

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