

# Baggage X-ray datasets with prohibited items: A survey

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## Abstract

This paper is devoted to the analysis of modern datasets of 2D X-ray images from X-ray screening machines used for the automatic detection of prohibited and dangerous items. Key free and conditionally free datasets are considered, including OPIXray, HiXray, EDS, X-ray FSOD, PIXray, PIDray, and STCray. Their scope, structure, class composition, and accessibility to the research community are analyzed. Special attention is paid to the specifics of X-ray images, including color coding of materials and the overlapping objects problem (occlusion). The main limitations of existing datasets are identified, such as class imbalance, limited accessibility, and insufficient representation of real inspection scenarios. The obtained results can be used in the selection and formation of training samples for tasks of automatic analysis of X-ray images.

## Keywords

security inspection, X-ray baggage screening, X-ray images, dataset, object detection, sustainable industry, life-cycle assessment

## 1. Introduction

Increasing of passenger traffic leads to new challenges in public security. In particular it relates to aviation security, one component of which is the screening of passengers' baggage using X-ray scanners. Examples of prohibited items are guns, knives, explosives, and others.

The effectiveness of detecting dangerous and prohibited items is one of the key factors in ensuring the safe and sustainable operation of air transport [1, 2]. Increasing the accuracy and reliability of screening procedures helps reduce risks for passengers and staff, supporting the social dimension of sustainable development [3, 4]. The use of intelligent X-ray image analysis technologies allows for increased control efficiency without a proportional increase in resource costs, which is consistent with the principles of economic and technological sustainability. In general, the development of automated systems for detecting prohibited items contributes to the formation of a safe, efficient, and sustainable aviation infrastructure in accordance with the goals of sustainable development.

Ensuring effective detection of prohibited items is directly related to the economic sustainability of the aviation industry [5, 6]. This is explained by the fact that the reliability of control systems affects the continuity and efficiency of the operation of airport infrastructure. Life cycle analysis of X-ray equipment allows to estimate the costs of its acquisition, operation, maintenance, repair, modernization and replacement throughout the entire period of use. Taking into account the technical condition and operational characteristics of X-ray equipment contributes to sound resource planning and timely decision-making on the repair, renewal or decommissioning of equipment [7, 8]. Integration of the assessment of the effectiveness of detection of prohibited items with the analysis of the life cycle of

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**Table 1**

The color Information of Different Objects under X-ray for HiXray, EDS and PIDray Datasets

| Color  | Material             | Typical examples  |
|--------|----------------------|-------------------|
| Orange | Organic Substances   | Plastics, Clothes |
| Blue   | Inorganic Substances | Irons, Coppers    |
| Green  | Mixtures             | Edge of phones    |

equipment creates the prerequisites for reducing total operating costs and increasing the economic sustainability of the aviation industry [9]. In general, the operation system of X-ray equipment for baggage screening includes the processes of technical condition monitoring, diagnostics, maintenance, repair and planning equipment replacement [10, 11]. Intelligent data processing technologies in these systems provide analysis of large arrays of operational information, detection of hidden patterns, assessment of the current state and forecasting. The use of such technologies creates the basis for the transition from reactive to predictive operation of X-ray equipment, increasing its reliability, availability and cost-effectiveness throughout the life cycle.

The paper [12] mentions that continuous analysis of large volumes of complex X-ray images can reduce the accuracy and attention of security operators, increasing the risk of missing dangerous items. Moreover, frequent personnel rotation requires considerable human resources and reduces operational efficiency. Applying of special methods for detection of prohibited items makes it possible to automate the inspection process. This methods include machine learning, computer vision and classical methods (i.e. correlation analysis, spectral analysis, Hough method). Deep learning using multilayer convolutional neural networks is a state-of-the-art approach in the computer vision in field of prohibited items detection in X-ray images.

Regardless of the method used, datasets are necessary for experimentation and comparative analysis. For real-world applications, these datasets must contain complex scenes. In X-rays images, there may be many items in the baggage, and prohibited items may be occluded or overlapped by other items. Despite the presence of a significant number of publications, the problem of systematization of datasets and assessment of their applicability remains unsolved. The scientific problem is the lack of a comprehensive analysis of existing datasets in terms of their structure, accessibility and suitability for practical application.

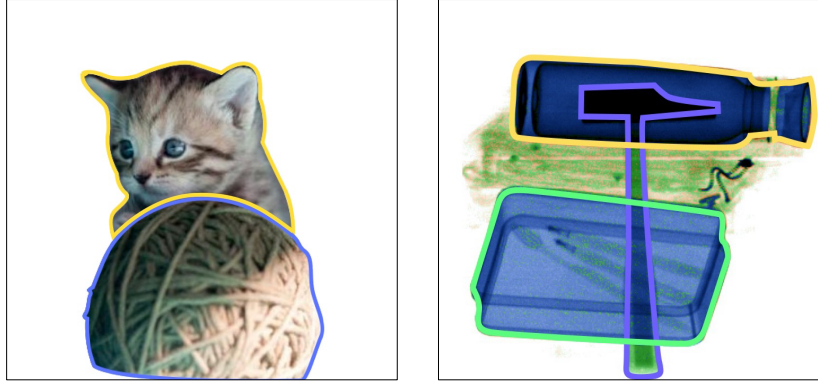
This survey is focused on 2D X-ray images only. Its purpose is analysis of modern datasets from the point of view of their structure, size, accessibility and applicability for the tasks of detection of prohibited items. Nowadays, many datasets with prohibited items exists. Many of them are for academic purposes only. No commercial use is allowed. They are publicly available or can be obtained upon request after signing the corresponding agreement. This paper contains survey for following datasets: OPIXray [12], HiXray [13], EDS [14], FSOD [15], PIDray [16, 17], PIXray [18] and STCray [19].

## 2. About X-ray images of baggage

First of all, it is necessary to note the essential difference between an X-ray image and an natural image [16]. It's presented in Figure 1.

Here, the color palette is used to determine the type of a material by its effective atomic number (see Table 1). It happens because X-rays have high penetrating capability, and different materials attenuate X-ray radiation at different levels. It leads to distinct color representations in the resulting images.

At the same time, in X-ray image the boundaries of overlapping and occluded objects are often merged. Especially in case of messy objects in the suitcase. X-ray images significantly differ from natural image in terms of object appearance and edge structure between foreground and background elements. It creates additional challenges in the analysis of baggage X-ray images in object detection tasks.



**Figure 1:** Comparison between the natural image (left) and X-ray image (right). Source: [16].

**Table 2**

Characteristics of Datasets. In "Access" Column "F" and "FR" Represents "Free" and "Free upon Request" Respectively. "L", "BB", "M" and "C" Represents "Labels", "Boundary Boxes", "Masks" and "Captions" Respectively

| Dataset    | Year | Access | Classes | Threat | Non-Threat | Total   | L | BB | M | C | Type      |
|------------|------|--------|---------|--------|------------|---------|---|----|---|---|-----------|
| OPIXray    | 2020 | FR     | 5       | 8 885  | 0          | 8 855   | + | +  | — | — | Synthetic |
| HiXray     | 2021 | FR     | 8       | 45 364 | 0          | 45 364  | + | +  | — | — | Real      |
| EDS        | 2022 | FR     | 10      | 14 219 | 0          | 14 219  | + | +  | — | — | Real      |
| X-ray FSOD | 2022 | FR     | 20      | 12 333 | 0          | 12 333  | + | +  | — | — | Real      |
| PIDray-21  | 2021 | F      | 12      | 47 677 | 0          | 47 677  | + | +  | + | — | Real      |
| PIDray-23  | 2023 | F      | 12      | 47 677 | 76 809     | 124 486 | + | +  | + | — | Real      |
| PIXray     | 2023 | F      | 15      | 5 046  | 0          | 5 046   | + | +  | + | — | Real      |
| STCray     | 2025 | F      | 20      | 45 693 | 949        | 46 642  | + | +  | + | + | Real      |

### 3. Survey of popular datasets

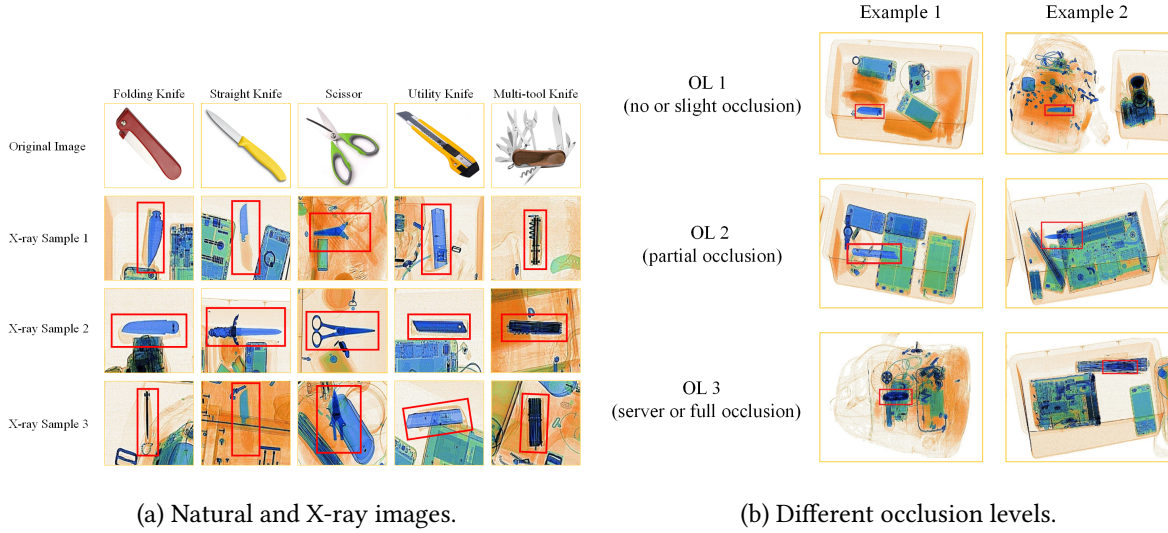
Summarized information about considered dataset is represented in Table 2. All of them are in freely available or provided upon request. These datasets may be used in academic purposes only. These datasets were acquired by real X-ray scanners except OPIXray. For this purpose, the scientists collaborated with real-world airports security inspection, involving professional security inspector or volunteers to annotating data. In case of volunteers involving they took special course about analysis of X-ray images and data annotating.

Literature analysis on considered datasets shows that dataset creation is resource-intensive task, which requires significant financial and organizational resources. Find an airport that agrees to cooperate. Afterward it's needed to involve people to annotate such a large volume of data. The considered datasets were developed to support specific mathematical models rather than being created as standalone datasets. And these works were done with grant funds. But datasets have been already created. So they can be used in other experiments.

#### 3.1. Group of datasets from Beihang University

A group of datasets developed by a team of scientists from Beihang University in China is particularly notable. Four datasets from this group are considered in this survey: OPIXray [12], HiXray [13], EDS [14] and X-ray FSOD [15].

In addition to the scientific publications, a GitHub repository [20] is available. It provides a brief description of the datasets along with instructions for obtaining access. They can be obtained after



**Figure 2:** Samples of X-ray images in OPIXray dataset. Source: [12].

signing the corresponding Commitment. The Commitment form requires information about the institution, research team, homepage, and contact email.

### 3.1.1. Dataset OPIXray

OPIXray [12] stands for Occluded Prohibited Items X-ray. This dataset was developed for implementation of model of object detection in occlusion conditions.

The OPIXray dataset includes 5 categories of cutting tools (cutters): "Folding Knife", "Straight Knife", "Scissors", "Utility Knife", and "Multi-tool Knife". The dataset contains 8,885 X-ray images with prohibited items in JPG format with a resolution of 1225\*954. On average, there is one prohibited item per image. Samples of X-ray images are shown in Figure 2a. The dataset is divided into training set (80%) and test set (20%). Special attention is paid to occlusion. Thus, the testing set is divided into three subsets, as shown in Figure 2b. In the Occlusion Level 1 (OL1) subset, prohibited items are not occluded or are barely occluded. The Occlusion Level 2 (OL2) subset features partial occlusion. Finally, the Occlusion Level 3 (OL3) subset features complete or very strong occlusion. It is worth noting that the dataset contains 35 images, each of which contains more than one prohibited item. There are 30 in the training set and 5 in the testing set.

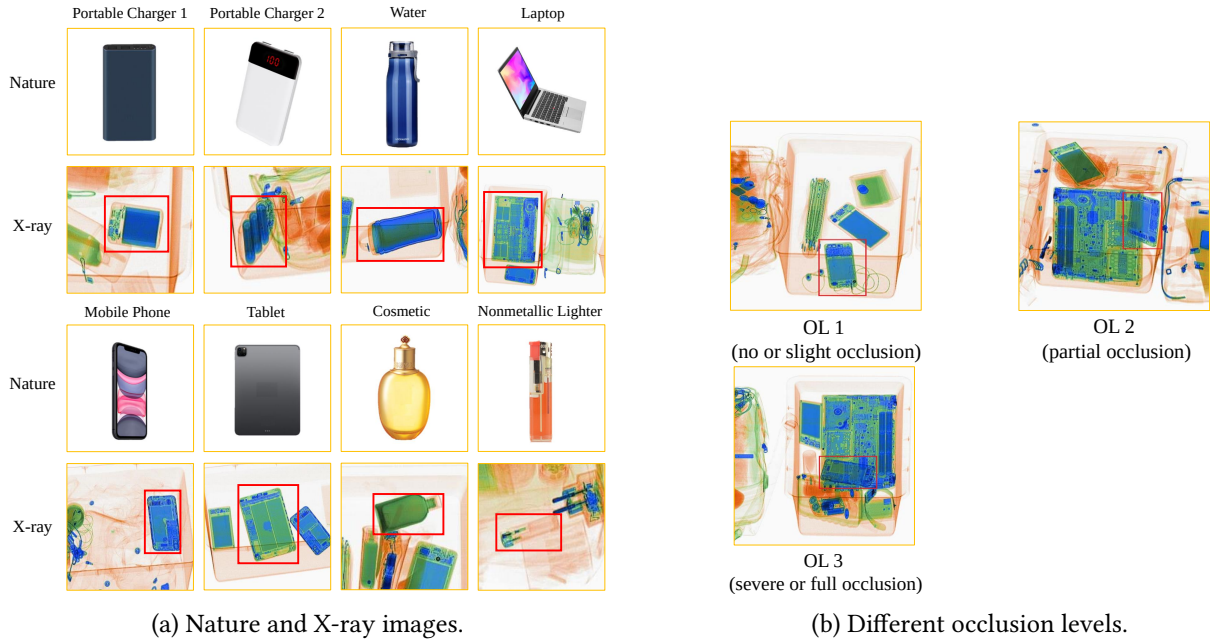
The backgrounds in all images were obtained from a security scanner. Prohibited objects were generated using specialized software. Such synthesized images are used at airports to train security personnel in recognizing prohibited items. The placement of synthesized objects was simulated to mimic real-world conditions as closely as possible, where baggage contains many items overlapping one another. Professional inspectors from the international airport manually annotated each prohibited item, which localized by a box-level annotation with a bounding box.

The PIXray dataset can be used to evaluate a model's ability to detect prohibited items in X-ray images, taking into account different levels of occlusion.

### 3.1.2. Dataset HiXray

HiXray [13] stands for High-quality X-ray. Like previous one this dataset also was developed for implementation of model of object detection.

The HiXray dataset contains 8 object categories: "Portable Charger 1", "Portable Charger 2", "Water", "Laptop", "Mobile Phone", "Tablet", "Cosmetic", and "Nonmetallic Lighter". The dataset contains 45,364 X-ray images with prohibited items. The images are stored in JPG format. The average resolution is 1200\*900 pixels. The maximum resolution is 2000\*1040 pixels. Samples of X-ray images are shown



**Figure 3:** Samples of X-ray images in HiXRay dataset. Source: [13].

in Figure 3a. The number of prohibited items is 102,928. Thus, there are an average of 2.27 instances per image. For information on the color palette, see Table 1. The dataset is divided into training set (approximately 80%) and test set (approximately 20%). As in the OPIXray dataset discussed earlier, significant attention is also paid here to object occlusion. Samples of images with such occlusions are shown in Figure 3b. The HiXRay dataset can be divided into three or more subsets according to different levels of occlusion.

The developers of the HiXRay dataset followed five principles.

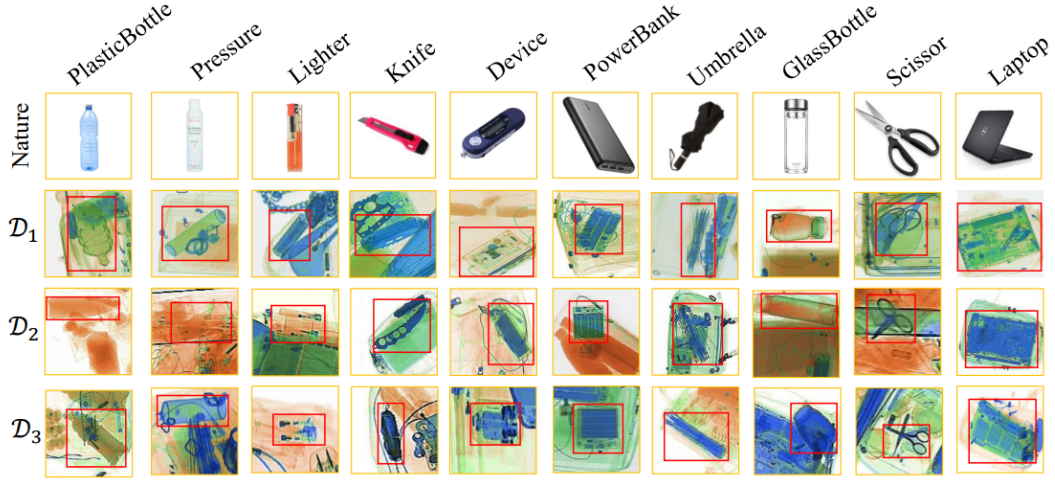
1. **Realistic source.** The dataset contains real X-ray images of baggage taken at an international airport.
2. **Data Privacy.** The standard de-privacy procedure has been applied. Personal information has been removed (name, place, etc.).
3. **Extensive Density.** Eight object categories were selected from real-life scenarios that frequently occur during baggage screening.
4. **Professional Annotation.** Professional airport security inspectors manually annotated each prohibited item, which is localized with a box-level annotation.
5. **Quality Control.** An annotation procedure similar to that used in the Pascal VOC competition [21] was applied.

All experts followed the same annotation procedure. To ensure comprehensive annotation, the accuracy of each annotation was verified by another expert, including for missed objects.

The HiXRay dataset can be used to evaluate models for detecting prohibited items in X-ray images. In addition to accounting for different levels of occlusion, there is also an option to test the detection of small objects. The dataset developers consider an object to be "small" if its bounding box covers less than 0.1% of the entire image. If an object's bounding box occupies more than 0.2%, it is considered large. Otherwise, the object is considered medium.

### 3.1.3. Dataset EDS

EDS [14] stands for Endogenous Domain Shift. This dataset was implemented to deal with endogenous shift among the domains (such as differences of color depth, texture, which mainly caused by hardware parameters, wear degrees, etc.,)



**Figure 4:** Samples of X-ray images in EDS dataset. 10 categories of objects from natural scenario and 3 different X-ray machines. " $\mathcal{D}_1$ ", " $\mathcal{D}_2$ " and " $\mathcal{D}_3$ " refer to "domain 1", "domain 2" and "domain 3", respectively. Source: [14].

The EDS dataset contains 10 object categories: "Plastic Bottle", "Pressure", "Lighter", "Knife", "Device", "Power Bank", "Umbrella", "Glass Bottle", "Scissors", and "Laptop". As can be seen, all these categories are commonly encountered in real life during baggage screening. The dataset contains 14,219 X-ray images with prohibited items. Sample images are shown in Figure 4.

The number of prohibited items is 31,655. Thus, there are an average of 2.22 instances per image. Information about the color palette is provided in Table 1. Three X-ray screening machines from different manufacturers and with varying lengths of service were used for data collection. Thus, the dataset contains three image domains. Items were randomly placed in pre-prepared packages. After the baggage is sent through the screening machine, it completely removes the background.

An annotation procedure similar to that used in the Pascal VOC competition [21] was applied. All experts used the same annotation procedure. To improve annotation accuracy, all annotators were divided into three groups. All images were randomly distributed among 2–3 specific groups for annotation. Finally, a separate group was specifically formed to verify the annotation results.

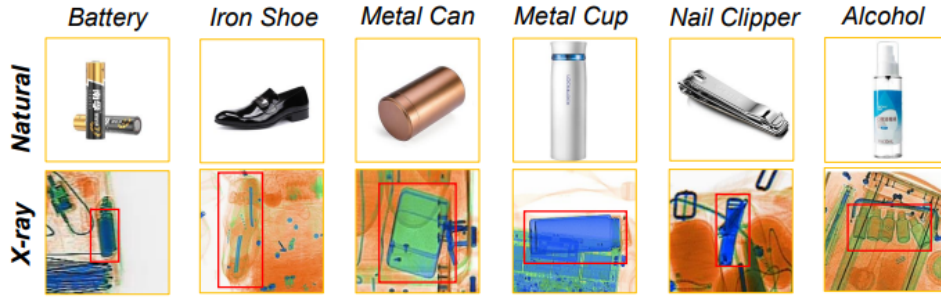
### 3.1.4. Dataset X-ray FSOD

Abbreviation FSOD [15] stands for few-shot object detection. This dataset has also been developed for object detection task. Its content focused on rare objects.

The X-ray FSOD dataset contains 20 object categories. Among them, 15 categories are base classes, while the remaining 5 are new classes introduced during evaluation. Images for 14 categories are taken from previous datasets.

Five categories were taken from the OPIXray dataset [12]: "Folding", "Straight", "Scissor", "Utility", and "Multi-tool". Five categories were taken from the HiXray dataset [13]: "Laptop", "Lighter", "Charger1", "Charger2", and "Phone". Four categories were taken from the EDS dataset [14]: "Plastic Bottle", "Glass Bottle", "Pressure", and "Umbrella". Six new categories: "Battery", "Iron Shoe", "Metal Can", "Metal Cup", "Nail Clipper", and "Alcohol". They are shown in Figure 5. Approximately 30 different objects were prepared for each new category. Dataset X-ray FSOD contains 12,333 X-ray images with prohibited items. The number of prohibited items is 41,704. Thus, there are an average of 3.38 instances per image. The dataset is divided into training set (approximately 80%) and test set (approximately 20%).

While working on the X-ray FSOD dataset, the developers discovered that some categories present in one of the publicly available datasets also appear in other datasets, but they are not annotated. For example, the "Laptop" category is present in the OPIXray dataset, but it is not annotated. At the same time, it is present in the HiXray dataset. The developers of the X-ray FSOD dataset cleaned the data. All instances across the 20 categories have been annotated.



**Figure 5:** Samples of X-ray images in X-ray FSOD dataset (new categories). Source: [15]

An annotation procedure similar to the one used in the Pascal VOC competition was applied [21]. Five annotators participated in the work. Initially, a 4-hour training course was conducted on detecting prohibited items in X-ray images. Labeling was performed using the "labelme" tool. Annotating a single image took 2 minutes. Annotators worked 8 hours per day. To minimize errors, each image was annotated twice and checked by a third inspector.

### 3.2. Dataset PIDray

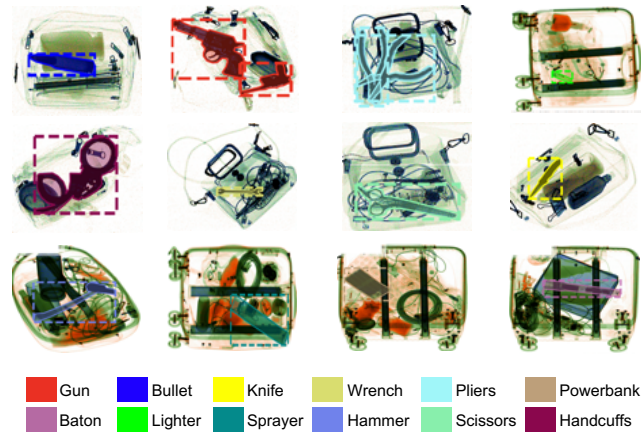
PIDray [16, 17] stands for prohibited items detection. This dataset has also been developed for prohibited items detection task.

The first version of the PIDray dataset was released in 2021, and the second in 2023. The dataset includes 12 categories of prohibited items: "Gun", "Knife", "Wrench", "Pliers", "Scissors", "Hammer", "Handcuffs", "Baton", "Sprayer", "Powerbank", "Lighter", and "Bullet". The 2021 and 2023 PIDray datasets contain 47,677 X-ray images with prohibited items. The 2023 version includes 76,809 images that do not contain prohibited items. Thus, the total number of X-ray images in the 2023 version is 124,486. Samples of images which contain prohibited items are shown in Figure 6a. All images are stored in PNG format. To ensure diversity, 2 to 15 examples of each category have been prepared. The dataset is divided into training set (approximately 60%) and test set (approximately 40%). Three detection difficulty levels are distinguished: easy, hard, and hidden (see Figure 6b). The easy level means that the image contains one and only one prohibited item. The hard level means that the image contains more than one prohibited item. The hidden level means that the image contains intentionally concealed prohibited items.

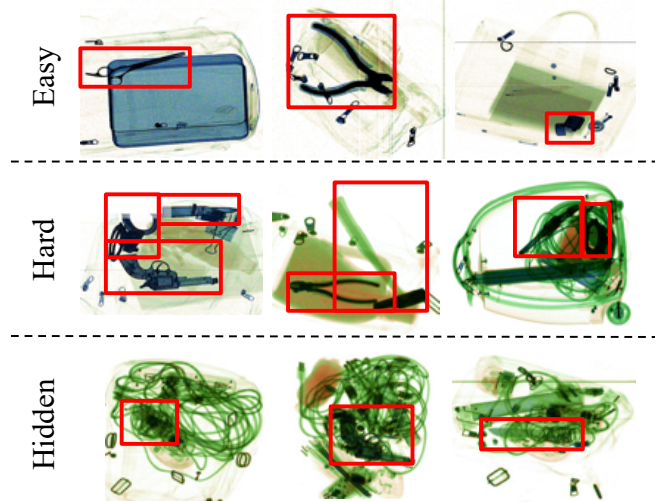
The PIDray dataset was collected at real-world screening locations such as airports, subway stations, and train stations. Volunteers were recruited who agreed to have their baggage included in the dataset for scientific, but not commercial, purposes. Three screening machines from different manufacturers were used. The resulting images exhibit certain variations in the size and color of objects and the background. After the baggage is sent through the screening machine, it completely crops the background on the left and right depending on the width of the baggage, keeping the height constant. Pre-prepared prohibited items were placed inside the passengers' baggage. To simplify the annotation process, the approximate location of the prohibited item was recorded. Volunteers were recruited to perform the annotation; special training courses were organized for them on detecting prohibited items in X-ray images. Initially, the dataset was cleaned of images that did not contain prohibited items. More than 10 volunteers were involved in labeling the dataset using the "labelme" tool. Annotating each image took approximately three minutes. Each volunteer worked 10 hours per day. In total, the annotation process took two months.

### 3.3. Dataset PIXray

PIXray [18] stands for Prohibited Item X-ray segmentation. This dataset has been developed for experiments with real-time prohibited item segmentation. It contains 5,046 X-ray images, in which 15 classes of 15,201 prohibited items are annotated as instance-level masks.



(a) Natural and X-ray images.



(b) Examples of test sets with different difficulty levels.

**Figure 6:** Samples of X-ray images in PIDray dataset (2021 year). Source: [16].

### 3.4. Dataset STCray

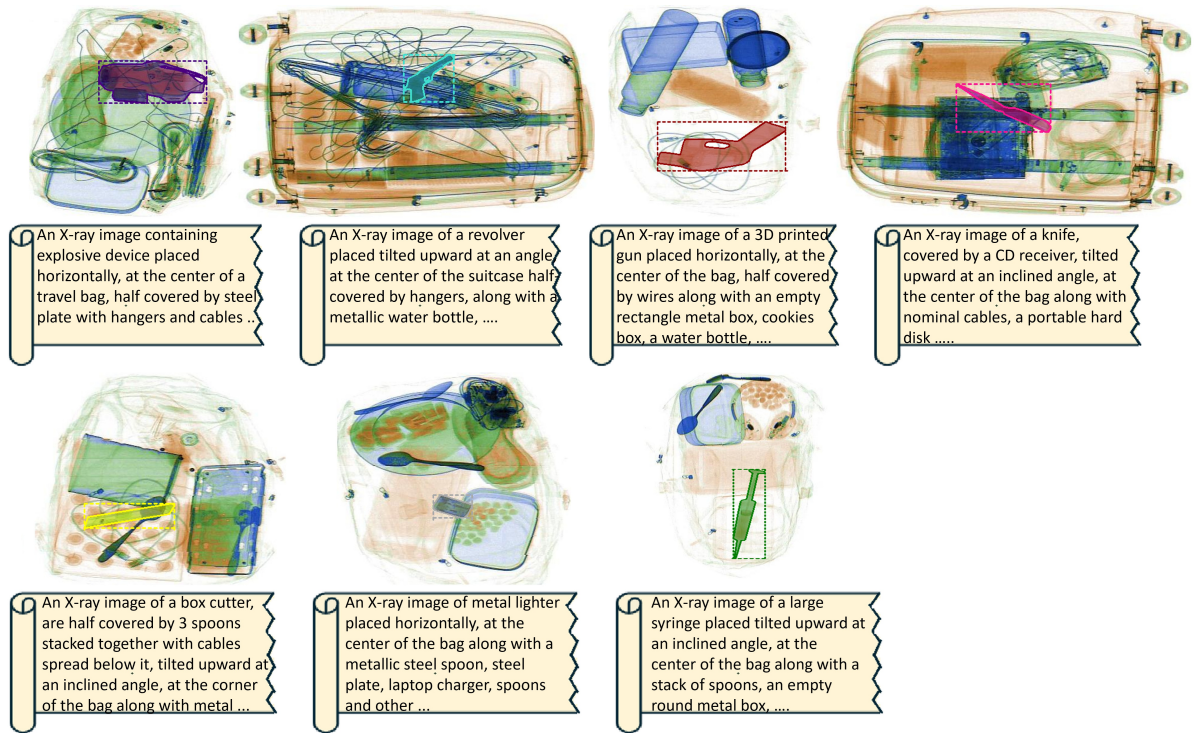
STCray [19] stands for Strategic Threat Concealment X-ray. This dataset was developed to train a domain-aware visual AI assistant. In comparison to previous datasets, this one includes text captions or descriptions of the images (see examples in Figure 7).

The STCray dataset features 20 categories of prohibited items: "Explosive", "Gun", "3D-printed Gun", "Knife", "Cutter", "Blade", "Shaving Razor", "Lighter", "Syringe", "Battery", "Nail Cutter", "Other Sharp Item", "Powerbank", "Scissors", "Hammer", "Pliers", "Wrench", "Screwdriver", "Handcuffs", and "Bullet".

To ensure realistic intra-class variations, each category includes a variety of instances that differ in shape and materials. For example, the "Lighter" category includes both metal and non-metal variants. For the "Wrench" category, the training set contains "Pliers Wrench" and "Crescent Wrench", while the test set contains new types of examples from this category: "Pipe Wrench" and "Self-adjusting Wrench". For the "Hammer" category, the training set contains "Brick Hammer" and "Claw Hammer", while the test set contains "Multi-tool Hammer" and "Framing Hammer".

The topic of intra-class variations also includes masking strategies. For example, in the training set, "Pliers" are masked using metallic grids or spoons. In the test set, however, they are masked using a box of Integrated Circuits (ICs). Or masking as ornaments using a chain.

A distinctive feature of this dataset is the presence of the "3D-printed Gun" category. The challenge in detecting objects in this category is their blurred outlines and non-standard material properties for



**Figure 7:** Sample images from STCray dataset with instance-level annotations and corresponding captions. Source: [19].

firearms. This results in prohibited 3D-printed objects blending in with other harmless objects on X-ray images. The "3D-printed Gun" category includes images of the following items: Liberator, Harlot, and Maverick in pepper-box style.

Another special category is "Explosive". The difficulty in detecting explosives lies in their non-standard shapes and multi-component structure (explosive charges enclosed in containers, detonators, activators, and power sources). In the "Explosive" category, there are two types: cohesive (compact) and dispersed (where individual components are either grouped together or spread throughout the baggage and connected by wires, effectively mirroring real-world settings).

The STCray dataset contains 46,642 X-ray images. Of these, the number of images without prohibited items is 2%, with one and only one prohibited item is 78%, and with multiple prohibited items is 20%. The dataset is divided into training (approximately 64%) and test (approximately 36%) sets.

The STCray dataset was developed to reflect real-world baggage screening conditions, taking into account systematic threat concealment strategies that mimic smuggling tactics and concealment practices. Airport baggage screening staff advised the developers of the STCray dataset on these issues. Prohibited items are intentionally placed and concealed among clutter and dense objects with varying levels of overlap, material density, and angular orientation.

Data collection was performed using an ANER K8065 X-ray scanner, which is used at airports, subway stations, and other security checkpoints. The tunnel dimensions are 800 mm wide and 650 mm high. The device is capable of penetrating steel to a depth of up to 40 mm, effectively detecting hidden objects inside dense materials. A MARS Microlab 5X120 computed tomography scanner was used to supplement the data. Its chamber can accommodate objects with a maximum diameter of 100 mm and a length of 350 mm. As a result, only some of the available prohibited items were scanned, namely: "Explosive", "Gun", "Knife", "Pliers", "Wrench", and "Scissors".

### 3.5. Other datasets

Neelanjan Bhowmik [22] collected information about a lot of datasets with X-ray images and scientific papers about X-ray security imaging in Computer Vision. He posted this material on GitHub. Unfortunately, it is not published as a scientific paper. There are short description for 20 dataset including 3D for years from 2015 till 2024.

## 4. Conclusions

The analysis of existing datasets with X-ray images of prohibited items has shown the existence of a significant number of such datasets. Among them there are quite a few datasets with open access or with open access upon prior request (as in the case of a group of high-quality datasets from Beihang University). They are intended to be used for research purposes only. Use for commercial purposes is not allowed. All the considered datasets were created for specific tasks. This proves that there are no standard datasets in the field of detection of prohibited items in X-ray images. Creation of such datasets requires significant financial and organizational resources. Nearly all considered datasets were created as part of grant-funded research projects.

It makes sense for the scientific community to continue working on the creation of high-quality standard datasets reflecting the realities in the field of security and threat detection, as well as their placement in the public access with the use for scientific purposes only.

Another direction is the creation of a library (catalog) of already existing datasets. The number of properties (attributes) of a dataset is much larger than presented in the table with datasets characteristics. We mean software implementation of the library (catalog) of datasets. It can be a desktop GUI application (implemented in the Python using the tkinter module), or as a web application (similar to Scopus). Such application should allow both novices and experienced specialists to quickly search for a suitable dataset. Over time, new datasets will be created. This makes it essential to have a development team to maintain and update such library.

## Declaration on Generative AI

The authors have not employed any Generative AI tools.

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