GDXray: The database of X-ray images for nondestructive testing

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Abstract In this paper, we present a new dataset consisting of 19,407 X-ray images. The images are organized in a public database called 𝔾𝔻𝕏ray that can be used free of charge, but for research and educational purposes only. The database includes five groups of X-ray images: castings, welds, baggage, natural objects and settings. Each group has several series, and each series several X-ray images. Most of the series are annotated or labeled. In such cases, the coordinates of the bounding boxes of the objects of interest or the labels of the images are available in standard text files. The size of 𝔾𝔻𝕏ray is 3.5 GB and it can be downloaded from our website. We believe that 𝔾𝔻𝕏ray represents a relevant contribution to the X-ray testing community. On the one hand, students, researchers and engineers can use these X-ray images to develop, test and evaluate image analysis and computer vision algorithms without purchasing expensive X-ray equipment. On the other hand, these images can be used as a benchmark in order to test and compare the performance of different approaches on the same data. Moreover, the database can be used in the training programs of human inspectors.

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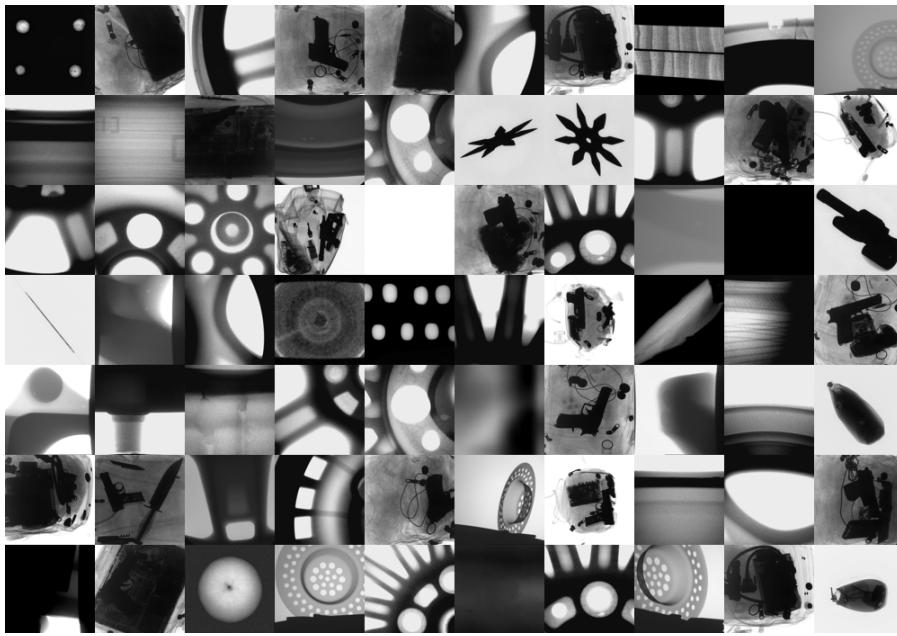
**Fig. 1** Random X-ray images of 𝔾𝔻𝕏ray database.

1 Introduction
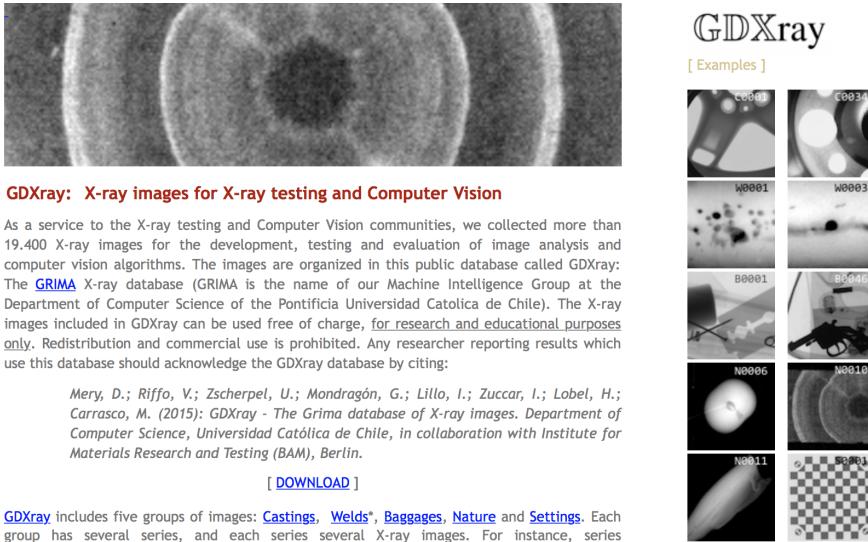
Public databases of X-ray images can be found for medical imaging[1], however, to the best knowledge of the authors, up until now there have not been any public databases of digital X-ray images for X-ray testing[2].

As a service to the X-ray testing community, we 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 a public database called 𝔾𝔻𝕏ray: The Grima X-ray database[3]. In order to illustrate our database, a random selection of 70 X-ray is shown in Fig. 1. The database includes five groups of X-ray images: castings, welds, baggage, natural objects and settings. Each group has several series, and each series several X-ray images. Some samples of each series are illustrated in Fig. 2. Most of the series are annotated or labeled. In those cases, the coordinates of the bounding boxes

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[1] See for example a good collection in http://www.via.cornell.edu/databases/.

[2] There are some galleries of X-ray images available on the web with a few samples, see for instance http://www.vidisco.com/ndt_solutions/ndt_info_center/ndt_x_ray_gallery with approximately 50 X-ray images.

[3] Grima, from *Grupo de Inteligencia de Máquina*, is the name of our Machine Intelligence Group at the Department of Computer Science of the Pontificia Universidad Católica de Chile http://grima.ing.puc.cl. The X-ray images included in 𝔾𝔻𝕏ray can be used free of charge, for research and educational purposes only. Redistribution and commercial use is prohibited. Any researcher reporting results which use this database should acknowledge the 𝔾𝔻𝕏ray database by citing this paper.

Fig. 2 Screenshot of 𝔾𝔻𝕏ray website. Some X-ray images of ten series are shown at the right side: `C0001` and `C0034` for castings, `W0001` and `W0003` for welds, `B0001` and `B0046` for baggage, `N0006` (cherry), `N0010` (wood) and `N0011` (salmon) for natural objects and `S0001` for settings (a calibration pattern).

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Table 1 Statistics of 𝔾𝔻𝕏ray database.

Groups	Series	Images	Size (MB)
Castings	67	2,727	307.5
Welds	3	88	209.4
Baggage	77	8,150	2,734.8
Nature	13	8,290	191.9
Settings	7	152	45.5
Total	167	19.407	3,489.0

of the objects of interest or the labels of the images are available. In Table 1 we can see some statistics. The size of 𝔾𝔻𝕏ray is 3.5 GB and it can be downloaded from our website (see Fig. 2).

In this paper, we will view the structure of 𝔾𝔻𝕏ray database, a description for each group (with some series examples), and some examples of applications that have been published using images of 𝔾𝔻𝕏ray.

2 Structure of the database

𝔾𝔻𝕏ray is available in a public repository. The repository contains 5 group folders one for each group: `Castings`, `Welds`, `Baggage`, `Nature` and `Settings`.

Table 2 Structure of $\mathbb{GDX}$ray.

Database	Groups		Series		X-ray images
GDXray →					
	Castings	→	C0001	→	C0001_0001.png ... C0001_0072.png
			⋮		
			C0067	→	C0067_0001.png ... C0067_0083.png
	Welds	→	W0001	→	W0001_0001.png ... W0001_0010.png
			⋮		
			W0003	→	W0003_0001.png ... W0003_0068.png
	Baggage	→	B0001	→	B0001_0001.png ... B0001_0014.png
			⋮		
			B0077	→	B0077_0001.png ... B0077_00576.png
	Nature	→	N0001	→	N0001_0001.png ... N0001_0013.png
			⋮		
			N0013	→	N0013_0001.png ... N0013_0006.png
	Settings	→	S0001	→	S0001_0001.png ... S0001_0018.png
			⋮		
			S0007	→	S0007_0001.png ... S0007_0029.png

For each group we define an initial: C, W, B, N and S respectively. As shown in Tab. 1, each group has several series. Each series is stored in an individual sub-folder of the corresponding group folder. The sub-folder name is Xssss, where X is the initial of the group and ssss is the number of the series. For example, the third series of group Castings is stored in sub-folder C0003 of folder Castings (see more examples in Fig. 2). The X-ray images of a series are stored in file Xssss_nnnn.png. Again Xssss is the name of the series. The number nnnn corresponds to the number of the X-ray image of this series. For example, the fifth X-ray image of series C0003 is C0003_0005.png and is stored in sub-folder Castings/C0003. The whole structure is summarized in Table 2. It is worth mentioning that all X-ray images of $\mathbb{GDX}$ray are stored in 'png' (Portable Network Graphics)[4] 8-bit grayscale format. Additional metadata for each series (such as description of the objects, parameters and description of X-ray imaging system, etc.) are given in an ASCII file called Xssss_readme.txt included in sub-folder Xssss, *e.g.*, C0003_readme.txt for series Castings/C0003.

3 Castings

The group Castings contains 2,727 X-ray images arranged in 67 series. The X-ray images were taken mainly from automotive parts (aluminum wheels and knuckles) using an image intensifier. Some examples are illustrated in Fig. 3. The details of each series are given in Table 3. Experiments on these data

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[4] See http://www.libpng.org/pub/png/.
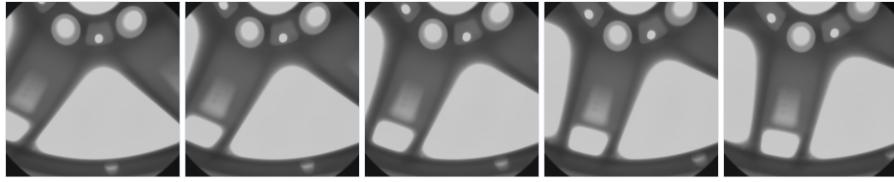
Fig. 3 Some X-ray images of an aluminum wheel (group `Castings` series `C0001`).

Table 3 Description of group 'Castings' of $\mathbb{GDX}$ray.

Series	Images	kpixels	Description	Additional
C0001	72	439.3	Wheel: Rotation each 5 degrees	Annotations for defects, calibration
C0002	90	44.5	Crops of C0001 with and without defects	Annotations for defects
C0003−C0043	37	439.3	Wheels with and without defects	Annotations for defects
C0044−C0051	54−77	65.5	Wheel with small drilled defects	Annotations for defects
C0052−C0054	17−31	440.8	Knuckle with low contrast defects	Annotations for defects
C0055	28	440.8	Sink strainer	Annotations for holes
C0056	10	440.8	Sink strainer high speed	
C0057	31	440.8	Knuckle with low contrast defects	Annotations for defects
C0058−C0067	10−83	440.8	Knuckle with small defects in motion	Annotations for defects

Table 4 Applications of series Castings.

Series	Application	References
C0001	Detection of defects in multiple views	[18, 10, 2, 28, 27, 14]
	Estimation of epipolar geometry with distortion	[16]
	Calibration of X-ray imaging system with image intensifiers	[18]
	Simulation of casting defects	[18]
C0002	Experiments on detection of defects in single views	[8, 4, 29, 15]
C0008	Simulation of casting defects	[6]
C0017	Simulation of casting defects	[7, 20]
C0032	Experiments on detection of defects in multiple views	[10]
C0037	Simulation of casting defects	[7, 20]
C0049	Image restoration in blurred X-ray images	[17]
C0054	Detection of casting on moving castings	[19]
C0055	Image restoration in blurred X-ray images	[17]
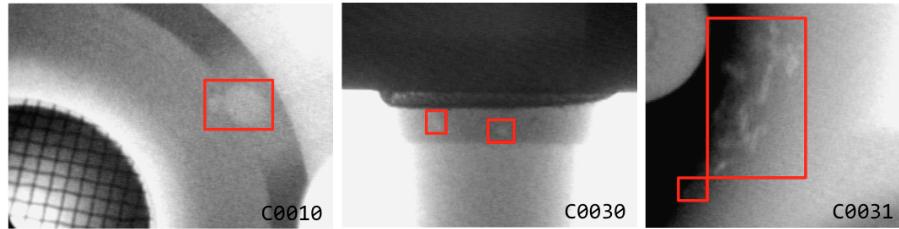
Fig. 4 Some annotated images showing bounding boxes of casting defects.

can be found in several publications as shown in Tab. 4. It is interesting to highlight that series `C0001` (see Fig. 3) contains not only a sequence of 72 X-ray images taken from an aluminum wheel by rotating its central axis in 5^0, but also annotations of bounding boxes of the ground truth of 226 small defects and the calibration matrix of each image that relates the 3D coordinates of the aluminum wheel with 2D coordinates of the X-ray image.

Table 5 Description of group 'Welds' of GDXray.

Series	Images	kpixels	Description	Additional
W0001	10	3323.8	Selection of 10 images of W0003	Annotations for defects. See W0002.
W0002	10	3323.8	Binary ideal segmentation of images of W0001	
W0003	68	6693.8	Radiographs from a round robin test performed by BAM	Excel file with real-values

Table 6 Applications of series Welds.

Series	Application	References
W0001	Detection of defects in welds	[1,13,11,5]
	Simulation of welding defects	[20,11]
W0002	Evaluation of performance of detection algorithm	[1]
W0003	Detection of defects in welds	[26,31]

4 Welds

The group Welds contains 88 images arranged in 3 series. The X-ray images were taken by the BAM Federal Institute for Materials Research and Testing, Berlin, Germany[5]. Some examples are illustrated in Fig. 5. The details of each series are given in Table 5. Experiments on these data can be found in several publications as shown in Tab. 6. It is interesting to highlight that series W0001 and W0002 (see Fig. 5) contains not only 10 X-ray images selected from the whole BAM database (series W0003), but also annotations of bounding boxes and the binary images of the ground truth of 641 defects.

Series W0003 contains a collection of 67 digitized radiographs from a round robin test on flaw recognition in welding seams. The NDT films (used with lead screens) were exposed according to ISO 17636-1, testing class A. After development they have been scanned with a LASER scanner LS85 SDR from Lumisys using digitization class DB-9 according to ISO 14096-2. The original 12 bit data depth was rescaled to 8 bits with a linear LUT proportional to optical film density by visual adjustment to the image content. This ensures that all necessary flaw information is still in the 8 bit images[6]. The pixel size is 40.3 micron (630 dpi). The images are 8 bit gray values. In addition, in this directory the file 'real-values.xls' contains the true data and the flaw designations according to ISO 6520 and ISO 5817. These true data have been generated using weld sections of 1 cm width starting from the indicated Zero point.

5 Baggage

The group Baggage contains 8,150 X-ray images arranged in 77 series. The X-ray images were taken from different containers such as backpacks, pen cases,

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[5] The X-ray images of series W0001 and W0003 are included in GDXray thanks to the collaboration of the BAM Federal Institute for Materials Research and Testing, Berlin, Germany http://dir.bam.de/dir.html.

[6] The original images in TIFF format are available also in series W0003 as files RRT01.zip (the first 31 images) and RRT02.zip (the last 36 images).
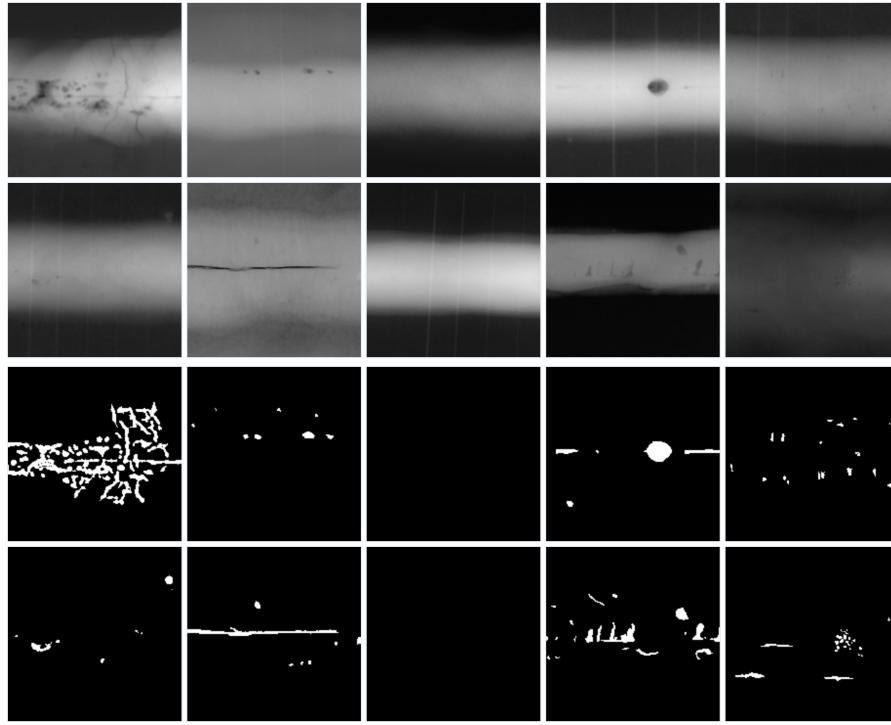
Fig. 5 Some images of group `Welds` series `W0001` (X-ray images) and `W0002` (ground truth).

wallets, etc. Some examples are illustrated in Fig. 6 and 7. The details of each series are given in Table 7. Experiments on these data can be found in several publications as shown in Tab. 8. It is interesting to highlight that series `B0046`, `B0047` and `B0048` (see for example Fig. 6) contains 600 X-ray images that can be used for automated detection of handguns, shuriken and razor blades (bounding boxes for these objects of interest are available as well). In this case, the training can be performed using series `B0049`, `B0050` and `B0051` that includes X-ray images of individual handguns, shuriken and razor blades respectively taken from different points of view as shown in Fig. 7.

6 Natural objects

The group Nature contains 8,290 X-ray images arranged in 13 series. The X-ray images were taken from different natural objects such as salmon filets, fruit and wood pieces. Some examples are illustrated in Fig. 9 and 10 The details of each series are given in Table 9. Experiments on these data can be found in several publications as shown in Tab. 10. It is interesting to highlight that series `N0012` and `N0013` (see Fig. 11) contains not only 6 X-ray images of salmon filets, but also annotations of bounding boxes and the binary images

Fig. 6 Some X-ray images of a bag containing handguns, *shuriken* and razor blades (group `Baggage` series `B0048`).
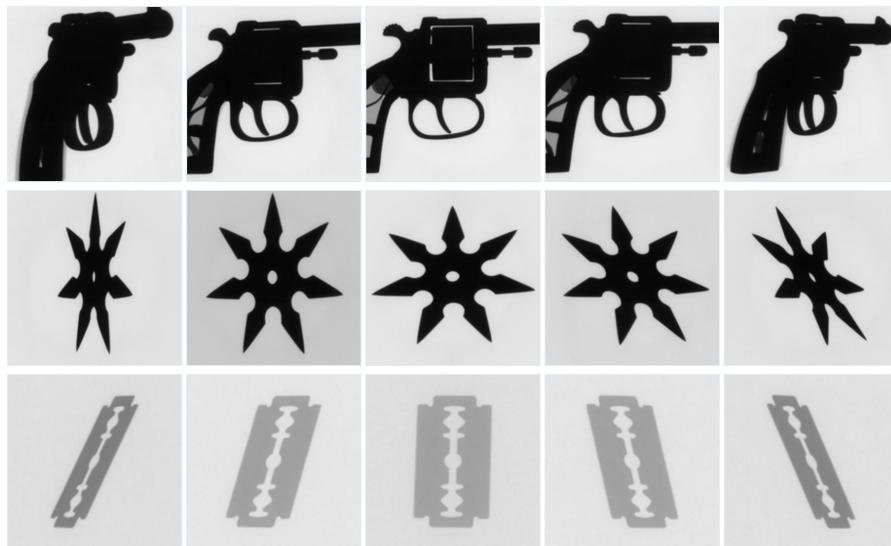
Fig. 7 Some X-ray images of handguns (series `B0049`), *shuriken* (series `B0050`) and razor baldes (series `B0051`) of group `Baggage`.

of the ground truth of 73 fish bones. For training proposes, there are more than 7,500 labeled small crops (10 × 10 pixels), of regions of X-ray of salmon filets with and without fish bones in series `N0003`.

7 Settings

The group Settings contains 151 X-ray images arranged in 7 series. The X-ray images were taken from different calibration objects such checkerboards and
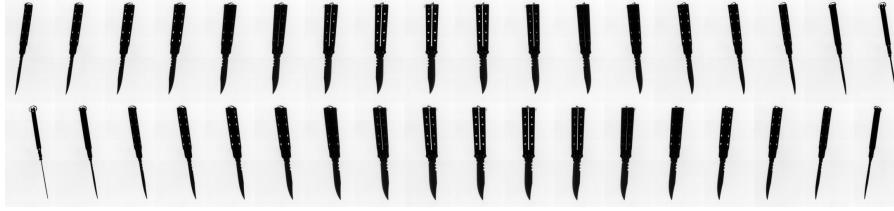
Fig. 8 A knife was rotated in 1^0 and by each position an X-ray image was captured. In this figure, X-ray images at $0^0, 10^0, 20^0, \ldots 350^0$ are illustrated (see series `B00008` of group `Baggage`).

Table 7 Description of group 'Baggage' of $\mathbb{GDX}$ray.

Series	Images	kpixels	Description	Additional
B0001–B0006	9–14	722.5-5935.1	Pen case with several objects	Annotations for objects
B0007	20	129.6	Razor blade for training	
B0008	361	745.8	Rotation of a knife in 1^0	
B0009–B0043	4–19	276.6	Backpack with handgun and objects	Annotations for handguns
B0044	178	5935.1	Backpack with handgun	Calibration parameters
B0045	90	1287.0	Pen case in 90 positions	Annotations for razor blades
B0046–B0048	200	5412.0–5844.0	Backpack with handguns, shuriken, razor blades	Annotations for objects
B0049–B0051	100–200	165.6–759.5	Handguns, shuriken, and blades for training	
B0052–B0054	144	741.3	Shuriken with 6,7,8 points for training	
B0055–B0057	800–1600	16.9–18.1	200 4, 6, 8-image sequences of single objects	Labels
B0058	64	196.6	Crops of clips, springs, razor blades and others	Labels. See B0059
B0059	64	196.6	Binary ideal segmentation of images of B0058	Labels. Original images in B0058
B0060	2	5935.1	Images for dual-energy experiments	Annotations for shuriken
B0061–B0073	17–25	2856.1–3656.8	Razor blade in cases	Annotations for razor blades
B0074	37	2856.1	Rotation of a door key in 10^0	
B0075–B0077	576	1581.8–5935.1	Knife in 576 positions	

Table 8 Applications of series Baggage.

Series	Application	References
B0005	Experiments on detection of pins in multiple views	[30, 10]
	Detection of razor blades using active vision	[30]
B0007	Training of a classifier of razor blades	[30]
B0009-43	Experiments on detection of handguns	[23, 3]
B0045	Experiments on detection of objects in multiple views	[12, 24]
	Active vision	[30]
B0055	Experiments on detection of objects in sequences of four views	[12]
B0056	Experiments on detection of objects in sequences of six views	[12]
B0057	Experiments on detection of objects in sequences of eight views	[12]
B0058	Training of a classifier for clips, springs and razor blades	[12, 24]
B0061-73	Detection of razor blades using active vision	[30]

Table 9 Description of group 'Nature' of $\mathbb{GDX}$ray.

| Series	Images	kpixels	Description	Additional
N0001	13	5935.1	Apples	
N0002	200	10.0	Cropped images of 100 × 100 pixels for fish bone detection	Labels
N0003	7,697	0.1	Cropped images of 10 × 10 pixels for fish bone detection	Labels
N0004	20	143.3	Static noisy images of a wood piece	
N0005	9	4076.7	Apples	Annotations for apples
N0006	27	5935.1	Cherries	Annotations for cherries
N0007	8	5935.1	Cherries	Annotations for cherries
N0008	3	5935.1	Kiwis	Annotations for cherries
N0009	39	585.0	Wood pieces	
N0010	99	83.6	Wood pieces	
N0011	163	5935.1	Salmon filets	
N0012	6	5935.1	Selected 6 images of N0011	Annotation for fish bones. See N0013
N0013	6	5935.1	Binary ideal segmentation of N0012	Original images in N0012
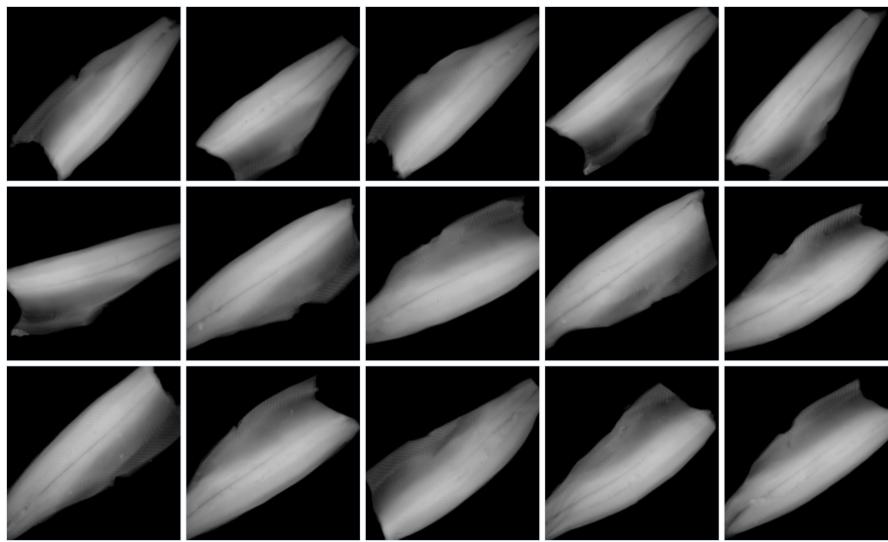
**Fig. 9** Some X-ray images of salmon filets (group `Nature` series N0011).
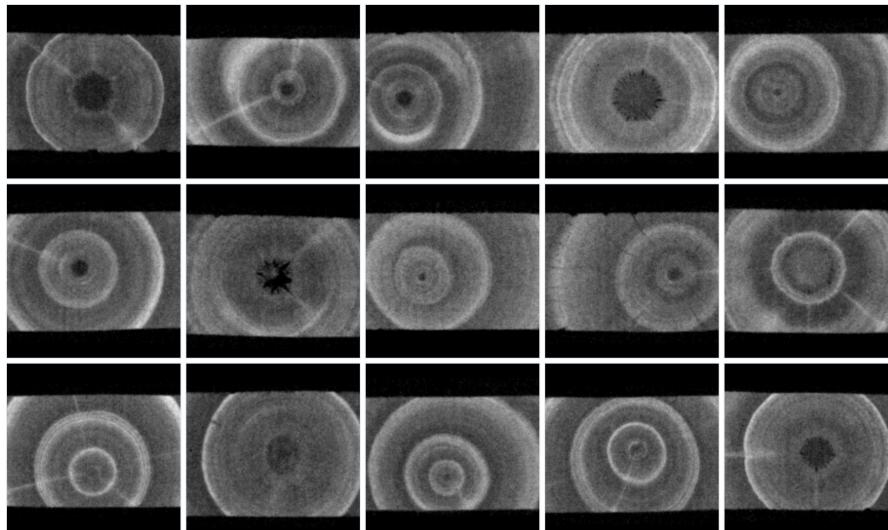
Fig. 10 Some X-ray images of wood (group `Nature` series N0010).

Table 10 Applications of series Nature.

| Series	Application	References
N0003	Automated design of a visual food quality system	[22]
N0003	Automated fish bone detection	[21]
N0008	Quality control of kiwis	[25]
N0011	Automated fish bone detection	[21]
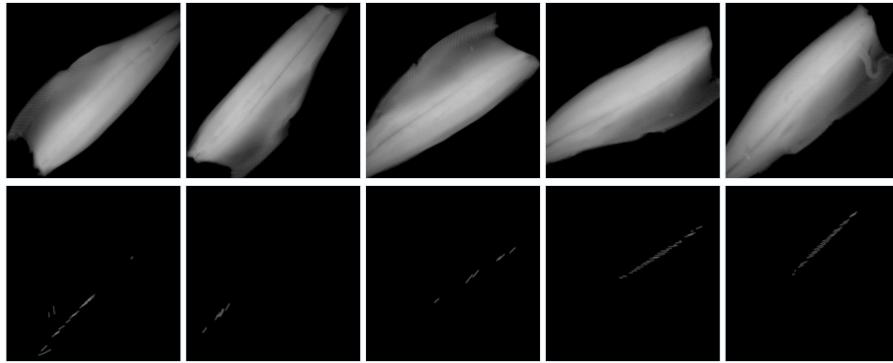
Fig. 11 Some images of group `Nature` series `S0012` (X-ray images of salmon filets) and `S0013` (ground truth for fish bones).
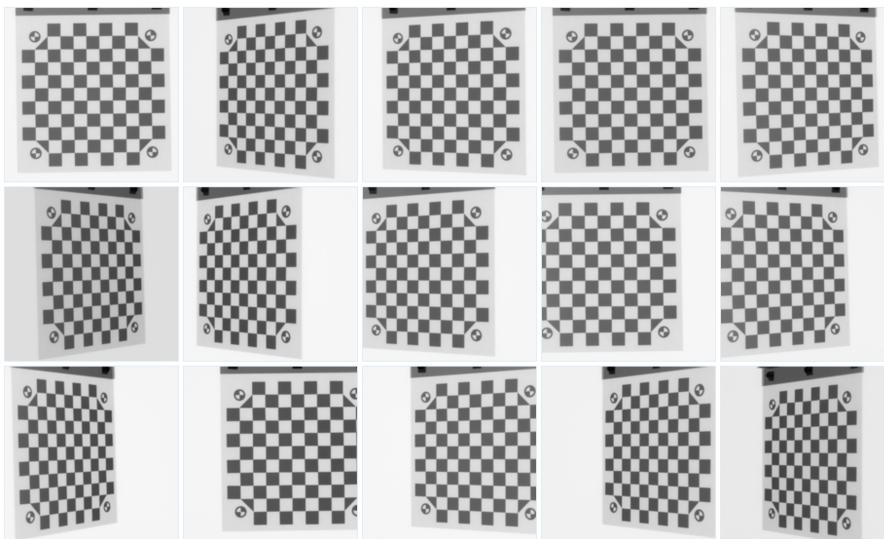

Fig. 12 Some X-ray images of a cooper checkerboard used by calibration (group `Settings` series `S0001`).

3D objects with regular patterns. Some examples are illustrated in Fig. 12. The details of each series are given in Table 11. Experiments on these data can be found in several publications as shown in Tab. 12. It is interesting to highlight that series `S0001` (see Fig. 12) contains not only 18 X-ray images of a copper checkerboard, but also the calibration matrix of each view. In addition, series `S0007` can be used for modeling the distortion of an image intensifier. The coordinates of each hole of the calibration pattern in each view are available, and the coordinates of the 3D model are given as well.

Table 11 Description of group 'Settings' of 𝔾𝔻𝕏ray.

Series	Images	kpixels	Description	Additional
S0001	18	5935.1	Checkerboard captured by flat panel	Calibration parameters
S0002	1	427.9	Regular grid captured by image intensifier	Coordinates of calibration points
S0003	36	440.8	Circular pattern in different positions	Manipulator coordinates, 3D coordinates
S0004	23	440.8	Circular pattern in different positions	Manipulator coordinates, 3D coordinates
S0005	27	440.8	Circular pattern in different positions	Manipulator coordinates, 3D coordinates
S0006	17	440.8	Circular pattern in different positions	Manipulator coordinates, 3D coordinates
S0007	29	440.8	Circular pattern in different positions	Coordinates of calibration points (2D & 3D)

Table 12 Applications of series Settings.

Series	Application	References
S0001	Calibration of a multiple view X-ray imaging system for active vision	[30]
S0002	Distortion model of an image intensifier	[16,18]
S0007	Explicit geometric model of a radioscopic imaging system	[9]

8 Conclusions

In this paper, we presented the details of a new public dataset called 𝔾𝔻𝕏ray. It consists of more than 19,400 X-ray images. The database includes five groups of X-ray images: castings, welds, baggage, natural objects and settings. Each group has several series and X-ray images with many labels and annotations that can be used for training and testing purposes in computer vision algorithms. To the best knowledge of the authors, up until now there have not been any public databases of digital X-ray images for X-ray testing.

In this paper, we explained the structure of the 𝔾𝔻𝕏ray database, we gave a description for each group (with some series examples), and we presented some examples of applications that have been published using images of 𝔾𝔻𝕏ray.

We believe that 𝔾𝔻𝕏ray represents a relevant contribution to the X-ray testing community. On the one hand, students, researchers and engineers can use these X-ray images to develop, test and evaluate image analysis and computer vision algorithms without purchasing expensive X-ray equipment. On the other hand, these images can be used as a benchmark in order to test and compare the performance of different approaches on the same data. Moreover, the database can be used in the training programs of human inspectors.

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