

Determination of a Firearm Model by the Marks on Cartridge Cases Using Convolutional Neural Networks

Presented by Pavel Giverts

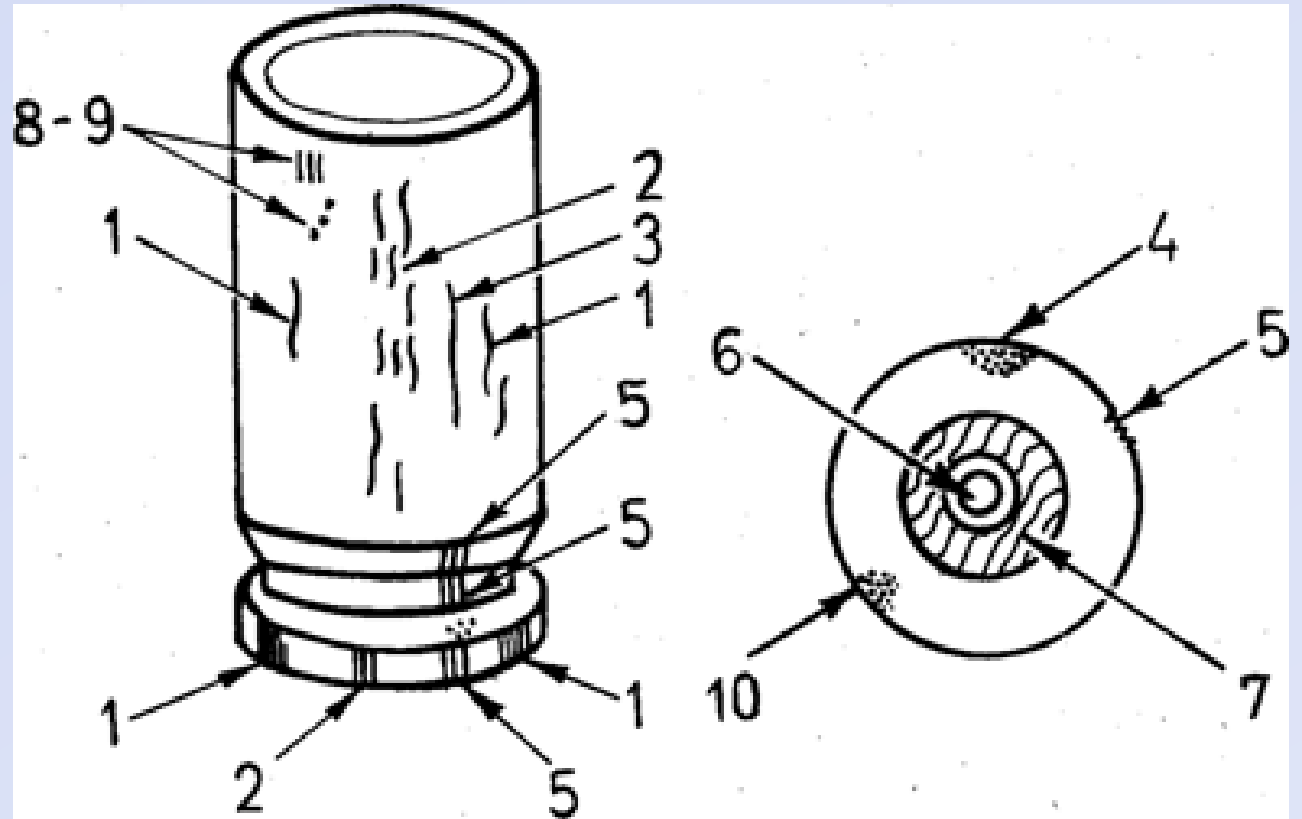
The project team



Pavel Giverts	— Israel
Fabiano Riva	— Switzerland
Alexandra Griber	— Israel
Daan Wintermans	— Switzerland
Joachim Rahm	— Germany
Volker Werner	— Germany
Gregory Jalabert	— France
Romualdas Svagzdys	— Lithuania
Qëndrim Topalli	— Kosovo

Class Characteristics

Class Characteristics - measurable features of a specimen which indicate a restricted group source. They result from design factors and are determined prior to manufacture. (AFTE Glossary)



Class Characteristics

ForFix Results logout home

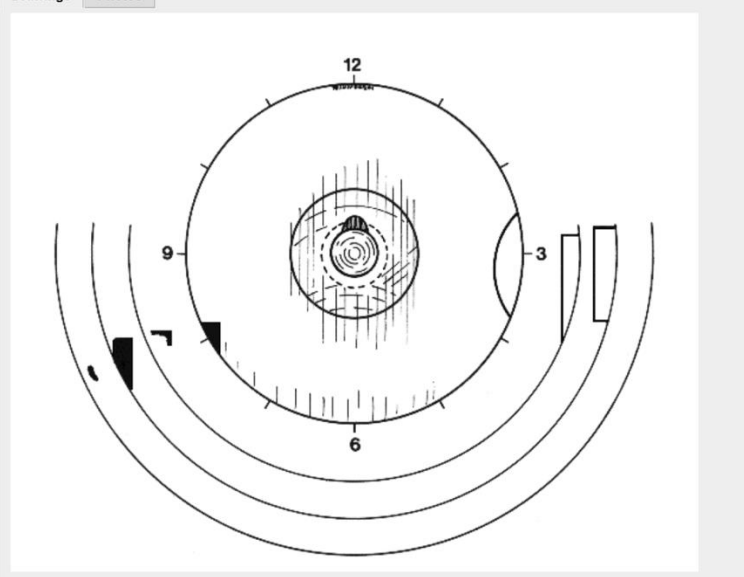
weapon

ID	Mod.Nr	SysNi	STAT	type	manufacturer	brand name	distributor	model	calibre
216	20955	12	B	P SL	FN			HP	9MM LUGER

remarks

Data of firearms | Cartridge data | Bullet data | Pictures | References | Addresses | Same Class

Drawings | Photos



record 1 from 2

record 1 from 1 back

Members Area - Databases - Class Characteristics Matrix (currently under construction!)

Cartridge Type: 9

Make: BERETTA

Model: 951

Breechface Marks: Parallel

Firing Pin Impressions: Aperture Flow Back, Circular/Spiral, Granular

Firing Pin Shape: Hemispherical

Aperture Shape: Circular

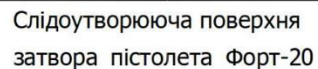
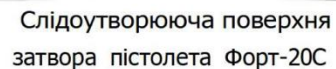
Shearing: No

Drag Mark: No

Ejector Marks: Edge of Rim, Pointed

Notes: Ejector location approx. 11:00/Extractor location approx. 6:00/Rifling 6R







The use of machine learning for the determination of a type/model of firearms by the characteristics on cartridge cases

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ARTICLE INFO

Keywords:

Forensic firearm identification
Class characteristics
Cartridge case
Machine learning
Convolutional neural networks (CNN)

ABSTRACT

Cartridge cases are commonly collected at crime scenes involving firearms. One of the stages in forensic examination is the determination of the type and model of firearms based on the class characteristics of these cartridge cases. A firearm examiner evaluates the class characteristics on the basis of their knowledge and experience, and by referring to collections of cartridge cases representing class characteristics of different firearms, special databases and reference books. However, this process is highly subjective. The novelty of this research is in developing objective methods of firearms determination by applying a machine learning approach. In this study, several Convolutional Neural Networks from Keras programming package were trained to determine the type/model of a firearm based on the class characteristics observed on cartridge cases from seven different categories of firearms. The prediction accuracies received by this method range from 71 to 81 percent for models based on different Convolutional Neural Networks, while using an ensemble of the machine learning models increased the accuracy to 88 %. The research demonstrates the efficacy of machine learning in enhancing accuracy and reducing subjectivity in firearm identification, highlighting its significant potential in forensic science applications.

1. Introduction

Criminal investigations of cases involving firearms routinely include examinations of the seized firearms and ammunition. These include identifying firearms, assessing their condition, restoring obliterated serial numbers and other analyses, while the examination of the cartridge cases involves the usage and microscopic comparison. This process aims to ascertain the number and the type/model of firearms that discharged these cartridge cases. Firearm examiners perform this determination based on class characteristics observed on the cartridge cases.

The AFTE Glossary [1] defines class characteristics as “Measurable features of a specimen which indicate a restricted group source. They result from design factors and are determined prior to manufacture”. These characteristics can be divided into two main groups: 1) originated from the design of the firearm, such as the position and the shape of an ejector impression, the size and the form of a firing pin impression, the

presence of shearing marks, etc.; and 2) arising from the manufacturing processes, such as milling, lathe, broaching, etc. which leave traces in the form of arcs, circles, parallel lines, etc. Firearm examiners analyze the observed characteristics and determine a possible type/model of the firearm from which the cartridge case has been discharged. Different databases can be used for this purpose, such as local collections of examples of cartridge cases discharged from known firearms, the AFTE Class Characteristics Matrix [2], ForFix (Forensic Firearms Expert Systems) [3], professional reference books [4,5] and articles published in professional journals [6–13]. During this process, examiner compares the characteristics observed on the cartridge case with the ones presented in these sources (Fig. 1).

However, this determination process has inherent subjectivity. Examiners rely on their experience, training, and available databases, resulting in high accuracy for familiar firearm models but potentially less accuracy for lesser-known ones. Therefore, developing a reliable

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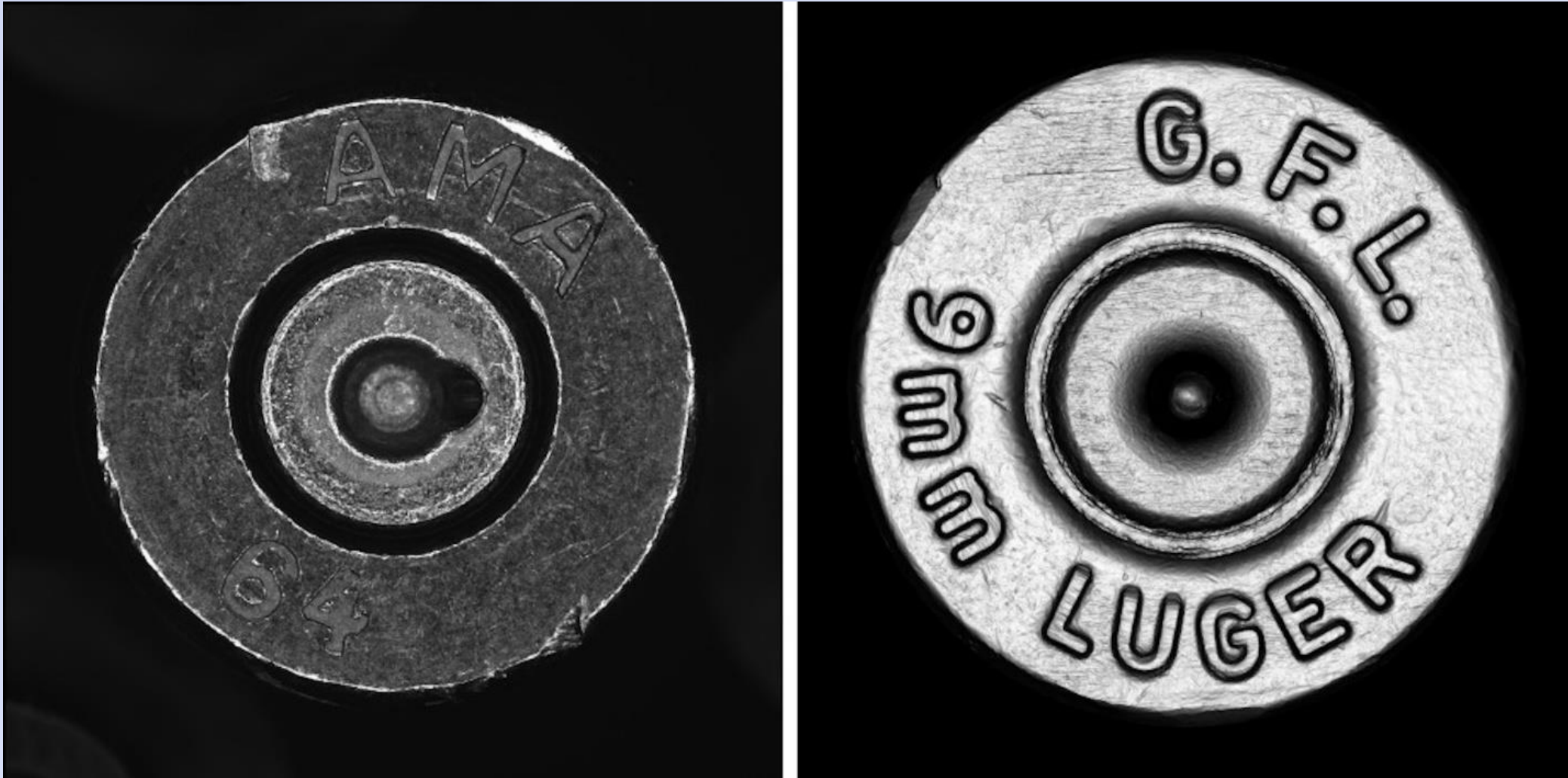
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The CNN training using 620 images for 7 groups of pistols



2D images of the
same cartridge case
exported from
EvoFinder™ system



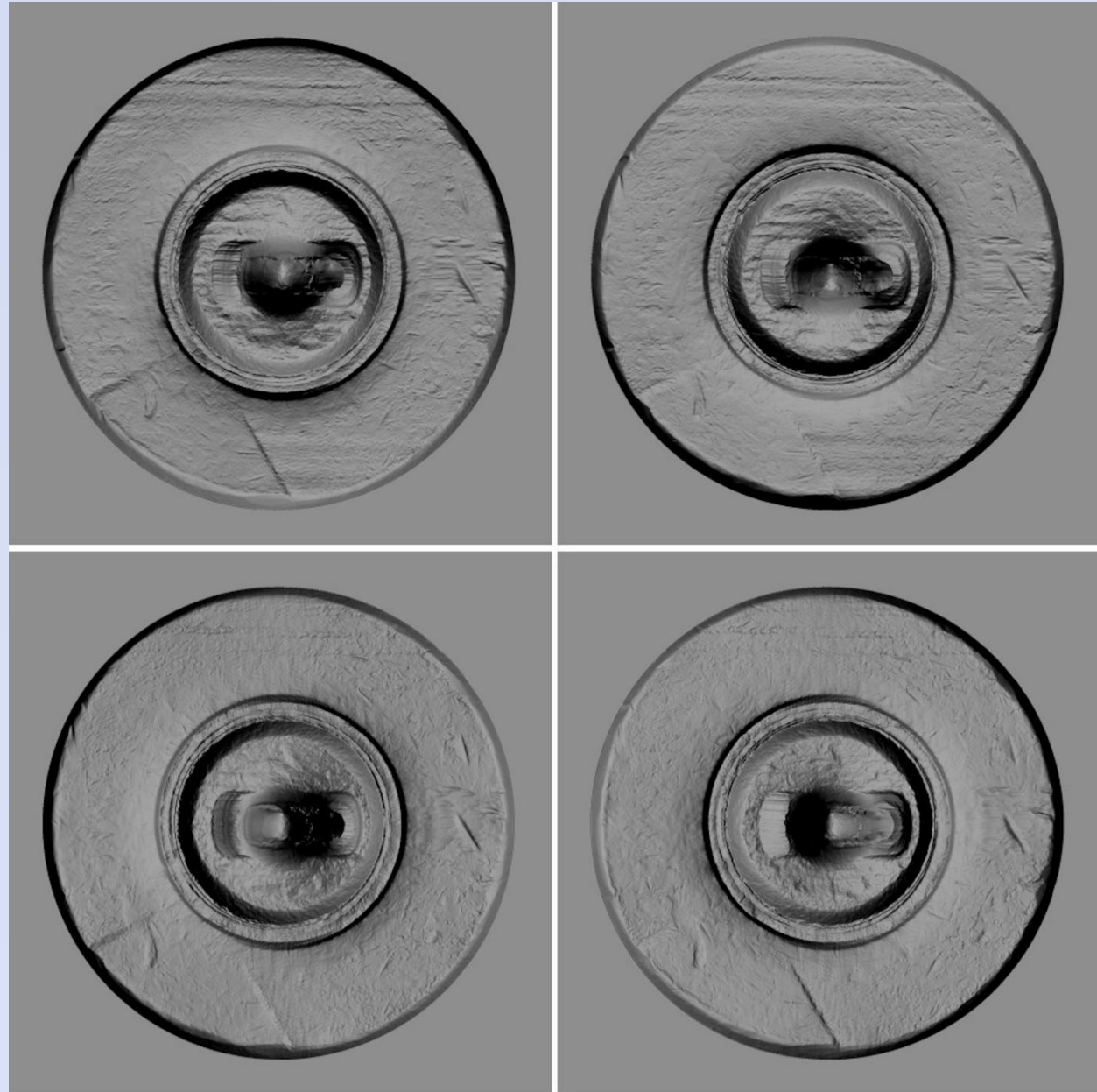


2D images exported from IBIS™: the left using older version (up to 3.3), the right using newer version 4

Examples of 2D
images made from one
X3P file exported from
EvoFinder™ system



Examples of 2D
images made from one
X3P file exported from
IBIS™



Examples of 2D
images made from one
X3P file exported from
BalScan™ system



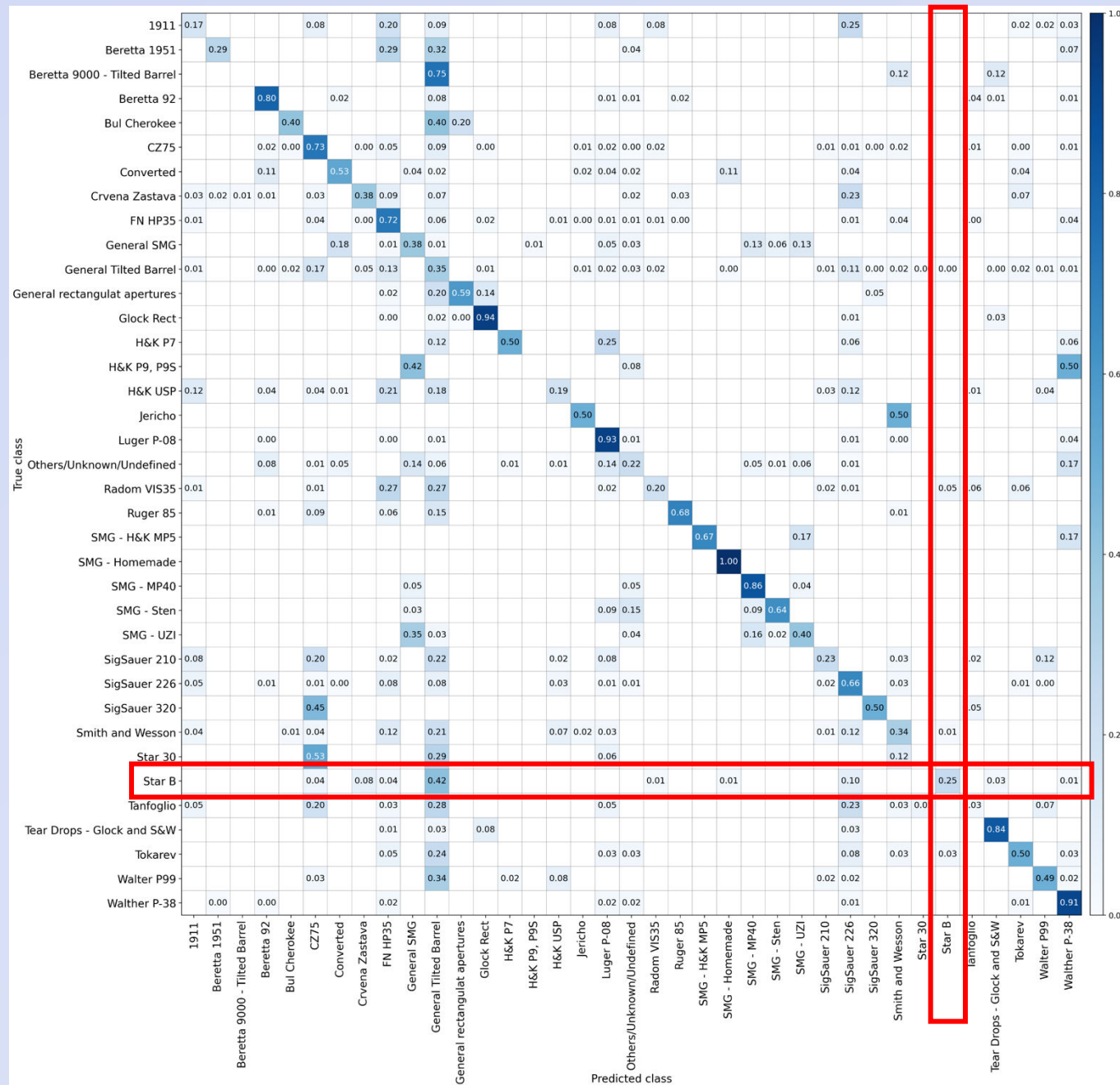
Image sources	Image numbers
2D EvoFinder™	24304
2D IBIS™ (old scanner)	1027
2D IBIS™ (new scanner)	542
converted from EvoFinder™ X3P	2392
converted from IBIS™ X3P	2156
converted from BalScan™ X3P	440

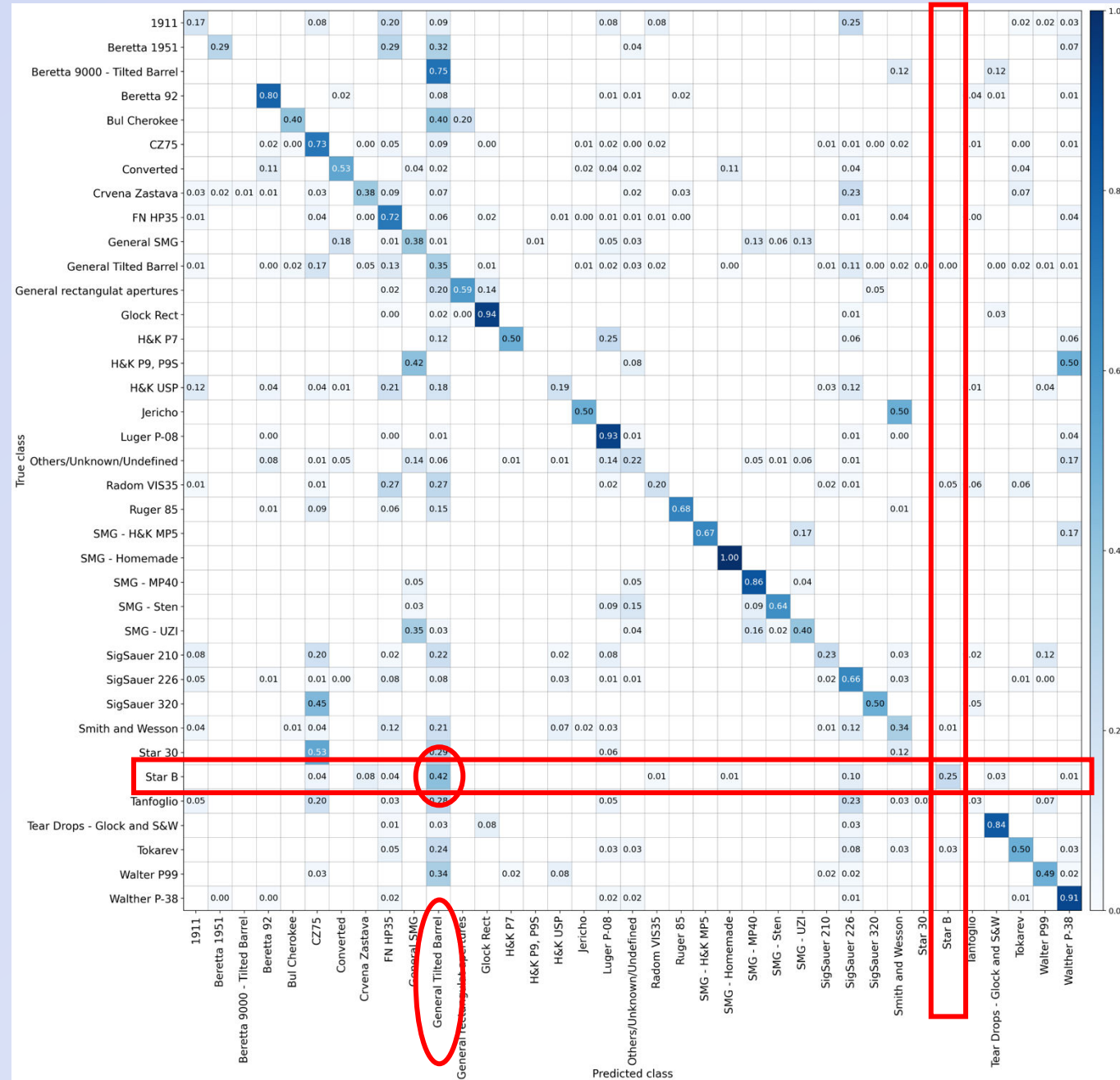
In total - 30930 images
- 4291 firearms

Class name	Number of images in subset		
	Train	Validation	Test
1911	316	65	65
Beretta 1951	95	18	28
Beretta 9000 (Tilted Barrel)	41	8	8
Beretta 92	647	136	148
Bul Cherokee	50	10	10
Converted	189	37	45
Crvena Zastava	424	96	96
CZ75	1940	439	450
FN HP35	1949	439	450
General rectangular apertures	211	50	44
General SMG	434	115	93
General Tilted Barrel	1443	307	316
Glock Rect	2668	576	576
H&K P7	88	16	16
H&K P9, P9S	58	8	12
H&K USP	246	49	68
Jericho	82	10	16
Luger P-08	2043	415	443

Class name	Number of images in subset		
	Train	Validation	Test
Others/Unknown/Undefined	685	152	132
Radom VIS35	313	66	81
Ruger 85	433	96	100
Sig Sauer 210	275	72	65
Sig Sauer 226	1161	256	262
Sig Sauer 320	87	16	20
SMG – H&K MP5	104	24	24
SMG – Homemade	304	42	76
SMG – MP40	259	53	56
SMG – Sten	107	25	33
SMG – Uzi	486	96	128
Smith and Wesson	579	105	113
Star 30	107	24	17
Star B	364	70	72
Tanfoglio	198	27	40
Tear Drops - Glock and S&W	619	140	136
Tokarev	320	72	76
Walther P99	337	72	65
Walther P-38	1885	417	410

Model	# of layers	Epochs	Top-1	Top-3
Xception	74	20	0.6294	0.7966
InceptionV3	94	15	0.6153	0.7845
InceptionResNetV2	200	13	0.6311	0.8049
ResNet50	53	16	0.6048	0.7814
DenseNet121	120	15	0.6157	0.7990
ConvNeXtTiny	81	17	0.6184	0.8033
ResNet101V2	104	20	0.6153	0.7864
EfficientNetV2S	170	15	0.6546	0.8170





Clear image

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Analyze

Predicted class: General Tilted Barrel

Confidence: 59.20%

Source: InceptionResNetV2

Models: InceptionResNetV2

Top-k comparison table (%)

Predicted class	InceptionResNetV2
General Tilted Barrel	59.2
Tanfoglio	26.93
CZ75	12.78

Clear image

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Top-k comparison table (%)

Predicted class	InceptionResNetV2
General Tilted Barrel	59.2
Tanfoglio	26.93
CZ75	12.78

Original class	Classes in domain
Any classes	Others/Unknown/Undefined
1911	General Tilted Barrel
Bul Cherokee	General Tilted Barrel, CZ75, Jericho, Tanfoglio
Crvena Zastava	General Tilted Barrel
CZ75	General Tilted Barrel, Jericho, Bul Cherokee, Tanfoglio
FN HP35	General Tilted Barrel
H&K USP	General Tilted Barrel
Jericho	General Tilted Barrel, CZ75, Bul Cherokee
Radom VIS35	General Tilted Barrel
Ruger 85	General Tilted Barrel
SigSauer 210	General Tilted Barrel, SigSauer 226
SigSauer 226	General Tilted Barrel, SigSauer 210
SigSauer 320	General Tilted Barrel

Original class	Classes in domain
Smith and Wesson	General Tilted Barrel
Star 30	General Tilted Barrel
Star B	General Tilted Barrel
Tanfoglio	General Tilted Barrel, CZ75, Jericho, Bul Cherokee
Tokarev	General Tilted Barrel
Walther P99	General Tilted Barrel
SMG - H&K MP5	General SMG
SMG - Homemade	General SMG
SMG - MP40	General SMG
SMG - Sten	General SMG
SMG - UZI	General SMG
Glock Rect	General rectangular apertures
Beretta 1951	Beretta 92
Beretta 92	Beretta 1951

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Analyze

Model parameters and settings

Selected models info

Predicted class: CZ75

Confidence: 60.95%

Source: Ensemble

Models: InceptionResNetV2, InceptionV3, ConvNeXtTiny, DenseNet121, Xception

Aggregation: Mean of probabilities

Top-k comparison table (%)

Predicted class	Ensemble	InceptionResNetV2	InceptionV3	ConvNeXtTiny	DenseNet121	Xception
CZ75	60.95	12.78	91.1	99.96	2.42	98.47
General Tilted Barrel	20.76	59.2	2.28	0	42.29	0.01
Glock Rect	9.54	0.15	0.35	0	47.18	0
Tanfoglio	7.46	26.93	1.62	0	7.35	1.42
Others/Unknown/Undefined	0.73	0.23	3.32	0	0.09	0
Ruger 85	0.13	0.51	0.12	0.01	0	0.03
SigSauer 320	0.04	0.09	0	0.03	0.01	0.06

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Upload image



Analyze

Model parameters and settings

Selected models info

Predicted class: CZ75

Confidence: 60.95%

Source: Ensemble

Models: InceptionResNetV2, InceptionV3, ConvNeXtTiny, DenseNet121, Xception

Aggregation: Mean of probabilities

Top-k comparison table (%)

Predicted class	Ensemble	InceptionResNetV2	InceptionV3	ConvNeXtTiny	DenseNet121	Xception
CZ75	60.95	12.78	91.1	99.96	2.42	98.47
General Tilted Barrel	20.76	59.2	2.28	0	42.29	0.01
Glock Rect	9.54	0.15	0.35	0	47.18	0
Tanfoglio	7.46	26.93	1.62	0	7.35	1.42
Others/Unknown/Undefined	0.73	0.23	3.32	0	0.09	0
Ruger 85	0.13	0.51	0.12	0.01	0	0.03
SigSauer 320	0.04	0.09	0	0.03	0.01	0.06

Models in ensemble	Top-1	Top-3	Top-1 Domain	Top-3 Domain
Xception + InceptionV3 + InceptionResNetV2 + EfficientNetV2S	0.6615	0.8235	0.7518	0.9335
Xception + InceptionV3 + InceptionResNetV2 + EfficientNetV2S + ConvNeXtTiny	0.6580	0.8220	0.7484	0.9306
All 8 models together	0.6555	0.8137	0.7530	0.9275

HuggingFace.co - Firearm/Toolmark Image Classification Demo



<https://huggingface.co/spaces/pavelgiverts/firearms-determination>

Spaces

pavelgiverts / firearms-determination

like 0

Agents

Running

Logs

AppFilesCommunity 2Settings

Firearm / Toolmark Image Classification Demo

Загрузите изображение, выберите одну или несколько моделей и сравните вероятности по классам.

Panel width

Move the slider left or right to change the width of the image area and the results area.

Clear image

Upload image

Drop Image Here

- or -

Click to Upload

Analyze

Model parameters and settings

Selected models info

Top-k comparison table (%)

1	2	3

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Analyze

Model parameters and settings

Models to use



EfficientNetV2S



InceptionResNetV2



InceptionV3



Xception



ConvNeXtTiny



ResNet101V2



ResNet50



DenseNet121

True label (optional)

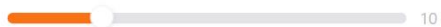
[Not selected]

Top-K to evaluate / display

3



1



10

Top-k comparison table (%)

1

2

3



Expert Working Group
Firearms / GSR

Clear image

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Top-k comparison table (%)

1

2

3

Analyze

Model parameters and settings ▼

Models to

☒ EfficientNetV2S

☐ InceptionResNetV2

☐ InceptionV3

☐ Xception

☐ ConvNeXtTiny

☐ ResNet101V2

☐ ResNet50

☐ DenseNet121

True label (optional)

[Not selected] ▼

Top-K to evaluate / display

3

↺

1



10



Expert Working Group
Firearms / GSR

Clear image

Upload image



Analyze

Model parameters and settings

Models to use

☒ EfficientNetV2S

☐ InceptionResNetV2

☐ InceptionV3

☐ Xception

☐ ConvNeXtTiny

☐ ResNet101V2

☐ ResNet50

☐ DenseNet121

True label (optional)

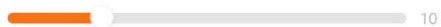
[Not selected]

Top-K to evaluate / display

3

↻

1



10

Top-k comparison table (%)

1

2

3



Expert Working Group
Firearms / GSR

Clear image

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Analyze

Model parameters and settings

Models to use



EfficientNetV2S



InceptionResNetV2



InceptionV3



Xception



ConvNeXtTiny



ResNet101V2



ResNet50



DenseNet121

True label (optional)

[Not selected]

Top-K to evaluate / display

3



1



10

Top-k comparison table (%)

1

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Analyze

Model parameters and settings

Models to use

☒ EfficientNetV2S

☐ InceptionResNetV2

☐ InceptionV3

☐ Xception

☐ ConvNeXtTiny

☐ ResNet101V2

☐ ResNet50

☐ DenseNet121

True label (optional)

[Not selected]

▼

Top-K to evaluate, display

3

🔄

1

10

Top-k comparison table (%)

1	2	3

True label (optional)

FN HP35

▼

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Analyze

Model parameters and settings

Selected models info

Selected models info

Model: EfficientNetV2S

Checkpoint:
model/EfficientNetV2S_trainable200_epoch15_valacc0.6900.pth

Timm model: tf_efficientnetv2_s

Image size: 500 x 500

Training model name: EfficientNetV2S

Best metrics:

- val_loss: 2.6313

- val_accuracy_top1: 0.6900

- val_accuracy_top3: 0.8261

- val_domain_accuracy_top1: 0.7568

- val_domain_accuracy_top3: 0.9108

Top-k comparison table (%)

1	2	3

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Analyze

Model parameters and settings

Models to use



EfficientNetV2S



InceptionResNetV2



InceptionV3



Xception



ConvNeXtTiny



ResNet101V2



ResNet50



DenseNet121

True label (optional)

[Not selected]

Predicted class: FN HP35

Confidence: 43.13%

Source: Ensemble

Models: EfficientNetV2S, InceptionV3, Xception, InceptionResNetV2

Aggregation: Mean of probabilities

Top-k comparison table (%)

Predicted class	Ensemble	EfficientNetV2S	InceptionV3	Xception	InceptionResNet...
FN HP35	43.13	100	62.85	8.51	1.18
General Tilted Barrel	27.84	0	10.53	2.09	98.75
Smith and Wesson	23.97	0	10.54	85.35	0.01
CZ75	3.97	0	11.89	3.96	0.05

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Analyze

Model parameters and settings

Models to use

- ☒ EfficientNetV2S ☒ InceptionResNetV2
☒ InceptionV3 ☒ Xception ☐ ConvNeXtTiny
☐ ResNet101V2 ☐ ResNet50 ☐ DenseNet121

True label (optional)

FN HP35

Predicted class: FN HP35

Confidence: 43.13%

Source: Ensemble

Models: EfficientNetV2S, InceptionV3, Xception, InceptionResNetV2

Aggregation: Mean of probabilities

Top-k comparison table (%)

Predicted class	Ensemble	EfficientNetV2S	InceptionV3	Xception	InceptionResNetV2
FN HP35	43.13	100	62.85	8.51	1.18
General Tilted Barrel	27.84	0	10.53	2.09	98.75
Smith and Wesson	23.97	0	10.54	85.35	0.01
CZ75	3.97	0	11.89	3.96	0.05

Class correspondence against True label

source	true_label	predicted_top1	strict_top1	strict_topk	domain_top1	domain_topk
Ensemble	FN HP35	FN HP35	Yes	Yes	Yes	Yes
EfficientNetV2S	FN HP35	FN HP35	Yes	Yes	Yes	Yes
InceptionV3	FN HP35	FN HP35	Yes	Yes	Yes	Yes
Xception	FN HP35	Smith and Wesson	No	Yes	No	Yes
InceptionResNetV2	FN HP35	General Tilted Barrel	No	Yes	Yes	Yes

Research publication

Forensic Science International Determination of Firearm Model by the marks on Cartridge Case Using Convolutional Neuron Networks --Manuscript Draft--



Manuscript Number:	
Article Type:	Original Research Article
Keywords:	firearms examination; firearm model determination; class characteristics; Convolutional Neuron Network; machine learning
Corresponding Author:	Fabiano Riva, PhD University Center of Legal Medicine Lausanne-Geneva Lausanne-Dorigny, VD SWITZERLAND
First Author:	Pavel Giverts, PhD
Order of Authors:	Pavel Giverts, PhD Alexandra Griber, BSc Daan Wintermans, MSc Joachim Rahm Volker Werner Gregory Jalabert Romualdas Svagzdys, MSc Qëndrim Topalli Fabiano Riva, PhD
Abstract:	<p>Determination of the possible firearm type and model based on class characteristics presented on fired cartridge cases is an important stage of forensic firearm examination, especially in the early stages of an investigation. Traditionally, such part of the examination requires time, resources and up-to-date databases. Currently the determination of the possible firearm type and model is subjective by nature. In order to improve this situation, the study focuses on the development of an objective method of class characteristics recognition based on the analysis of images of the headstamp area of cartridge cases by convolutional neural networks (CNN).</p> <p>A dataset of 30 930 images representing 4 291 firearms was collected from several automatic ballistic identification systems (ABIS) and divided into 37 classes. During the research eight CNN architectures were trained and evaluated: Xception, InceptionV3, InceptionResNetV2, ResNet50, DenseNet121, ConvNeXtTiny, ResNet101V2 and EfficientNetV2S.</p> <p>The evaluated models showed similar performance, with Top-1 accuracy of approximately 0.60–0.65 and Top-3 accuracy of approximately 0.78–0.82. When domain-based acceptance rules were applied to the account, similarities between classes, accuracy increased to approximately 0.69–0.73 for Top-1 and 0.90–0.925 for Top-3. Ensemble configurations provided a modest additional improvement, with the best ensemble reaching a domain-based Top-3 accuracy of 0.9335.</p> <p>Using the results of the research a free-access web-application for the analysis of images and the determination of possible firearm classes was developed.</p>
Opposed Reviewers:	

Further work

- **More data collecting**

Further work

- **More data collecting**
- **Developing multi-label model**

Further work

- **More data collecting**
- **Developing multi-label model**
- **Reviewing image labeling**

Further work

- **More data collecting**
- **Developing multi-label model**
- **Reviewing image labeling**
- **Working on the increase of accuracy**

Further work

- **More data collecting**
- **Developing multi-label model**
- **Reviewing image labeling**
- **Working on the increase of accuracy**
- **Developing new software including stand-alone version**



<https://huggingface.co/spaces/pavelgiverts/firearms-determination>

Questions?

Pavel Giverts

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