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# Iris Recognition: Fundamentals, Progress and Challenges

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# **Outline of Talk**

- Preamble
- Progress of Iris Recognition
  ✓ Iris image acquisition
  - ✓ Iris image preprocessing
  - ✓ Iris pattern recognition
- Applications of Iris Recognition
- Challenges and Future Directions

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## **Iris in the Context of Biometrics**



# **Human Iris**

- Iris is the ring-shaped colored membrane between the pupil and the sclera
- Protected by cornea but externally visible
- Highly textured



# **Iris Textures under Different Illumination**



- The uniqueness of iris texture comes from the random and complex structures such as furrows, ridges, crypts, rings, corona, freckles etc. which are formed during gestation
- The epigenetic iris texture remains stable after 1.5 years old or so

# **Iris Recognition**

• Acquisition, processing, analysis and comparison of iris patterns for personal identification



# **Why Iris Recognition?**



Unique





**Stable** 



**Non-intrusive** 





Hard to fake

# **Why Iris Recognition?**



# **Comparison with Other Biometric Modalities**

Biometrics	Universality	Uniqueness	Stability	Collectability	Accuracy	Acceptability	Security
Face	High	Low	Medium	High	Low	High	Low
Fingerprint	Medium	High	High	Medium	High	Medium	High
Hand	Medium	Medium	Medium	High	Medium	Medium	Medium
Vein	Medium	Medium	Medium	Medium	Medium	Medium	High
Iris	High	High	High	Medium	High	Medium	High
Retina	High	High	Medium	Low	High	Low	High
Handwriting	Low	Low	Low	High	Low	High	Low
Voice	Medium	Low	Low	Medium	Low	High	Low
Thermogram	High	High	Low	High	Medium	High	High
Odor	High	High	High	Low	Low	Medium	Low
Gait	Medium	Low	Low	High	Low	High	Medium
Ear	Medium	Medium	High	Medium	Medium	High	Medium
DNA	High	High	High	Low	High	Low	Low

# **History of Iris Recognition Research**



*Mostly from* A.K. Jain, K. Nandakumar and A. Ross, 50 Years of Biometric Research: Accomplishments, Challenges, and Opportunities. Pattern Recognition Letters (PRL), 2015.

# **Increasing Research on Iris Recognition**

#### **#** Papers and Patents



## **Market Potential of Iris Recognition**

#### IRIS RECOGNITION MARKET, BY REGION (USD BILLION)

#### Points to note:

- The global iris recognition market size is expected to grow from USD 2.3 billion in 2019 to USD 4.3 billion by 2024.
- APAC is expected to account for the largest share of the iris recognition market.



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-Source: © MarketsandMarkets, https://www.marketsandmarkets.com/Market-Reports/iris-recognition-market-141994093.html

## **Flowchart of Iris Recognition**



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# **Iris Image Acquisition**

VS



#### Non-trivial Problem



#### **Limited Depth of Field**



#### **Near-Infrared Illumination**



#### Variations in Location/Pose/Motion/Gaze

# **Close-range Iris Sensors**























IrisID iCAM TD100

HID Crossmatch I Scan 3



Panasonic BM-ET300

SecuriMetrics PIER 2.3





HID Crossmatch I SCAN2

Panasonic BM-ET500



IrisGuard IG-H100 IrisGuard IG-AD100



IrisKing IKEMB-110



IriTech IriShield BK 2121U



IrisKing IKAI1000

Eyelock NANO iXT







IrisKing IKUSB600





IrisStar S300-UC



















IrisStar S320-T1







# **Long-range Iris Sensors**



# **Our Journey in Developing Iris Sensors**



# **Limitations of the Existing Iris Sensors**



## **Iris Imaging With Expanded Capture Volume**



Kunbo Zhang, Zhenteng Shen, Yunlong Wang, Zhenan Sun. "All-in-Focus Iris Camera with a Great Capture Volume", IEEE International Joint Conference on Biometrics (*IJCB*), 2020. (*IJCB 2020 Google Best Paper Award Runner-Up*)

# **Spatiotemporal Multiplexing Imaging**



Kunbo Zhang, Zhenteng Shen, Yunlong Wang, Zhenan Sun. "All-in-Focus Iris Camera with a Great Capture Volume", IEEE International Joint Conference on Biometrics (*IJCB*), 2020. (*IJCB 2020 Google Best Paper Award Runner-Up*)

## **Deep Learning Assisted Iris Autofocus**



Leyuan Wang, Kunbo Zhang, Yunlong Wang, Zhenan Sun. "An End-to-End Autofocus Camera for Iris on the Move," IEEE International Joint Conference on Biometrics (*IJCB*), 2021.

# **CASIA Long-range (10m) Prototype**



# **CASIA Long-range (10m) Prototype**

Larger DoF	ę
Wider Fov	
Higher Resolution at a distance	
Active Imaging	
Multiple Persons	

Small DoF 20cm	<b>Narrow FoV</b> <10° (no PTZ)	Single person	-	Large Do 3.9 m@5	oF m	<b>Wid</b> 3	<b>le FoV</b> 60°	Multiple (≥3)
Model	Distance	Performance		Pers	on	User cooperation		
IOM, Sarnoff	2.4-3 m	0.2m x 0.4 m x 0.1 m, two cameras, 0.5 s/person			1		Standstill, walk (1m/s@5m)	
Eagle-Eyes, Retica	3-6 m	3 m x 2 m x 3 m, double cameras			1		Standstill	
CASIA	2.4-3 m	0.15 m x 0.15 m x 0.1 m, PTZ camera			1		Standstill	
CMU	12 m	0.97 m x 0.73 m @1 m			1		Standstill, walk (0.6m/s)	
SRI	25 m	0.305 m x 0.405 m@25 m, long focal zoom lens, O.D. 254 mm			1		Standstill	
iCAM D1000, Iris ID	0.5-1 m	0.2 m x 0.5 m x 0.5 m, vertical moving camera (50 mm)		1		Standstill		
S200P, Iristar	1-1.2 m	Height 1.3-1.95 m, DoF 30 cm, 2 s recognition			1		Standstill	
Versa F Max, Irisian	0.8-2 m	Height 1.2-2 m, PTZ camera, 1 s eye tracking, 3 s recognition			1		Standstill	
Ours	1–10 m	Height 0.8-2 m, 360°, single camera		≥3		Standstill, walk (1m/s@1-10 m)		

# **CASIA Long-range (10m) Prototype**



**Iris recognition process of multiple persons** 

### **CASIA Iris Image Database V4.0**

Http://biometrics.idealtest.org



**CASIA-Iris** 



CASIA-Iris-Distance

The CASIA Iris Database has been requested by and released to more than 30, 000 researchers from 170 countries or regions. It is one of the most widely used iris databases.

**ear texture** iris images

y iris/face

taset of one

in s image dataset

# **CASIA Iris Image Database V5.0-pre**



CASIA-Iris-Degradation (CASIA Long-range Prototype II)

Large-scale (over 36K images), composite iris degradation factors



CASIA-Iris-Africa (IrisKing IKUSBE30)

Collected in Nigeria, over 1K African subjects, various eye state



#### CASIA-Iris-Complex (CASIA Long-range Prototype I)

Diverse iris quality, multiple distances, cross-sensor







#### CASIA-Iris-High Throughput (IriStar S200P)

Iris image sequences, moving subjects, glasses on and off

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## **Flowchart of Iris Recognition**





### **Iris Detection**



# Is there an iris in the input image?

#### **Solutions to Iris Detection**



#### **Extended Haar features + Boosting learning**

## **Risk of Fake Iris Attacks**



## **Iris Liveness Detection: A Texture Solution**



# **Iris Image Classification for Iris Liveness Detection**



Zhenan Sun, Hui Zhang, Tieniu Tan, and Jianyu Wang, "Iris Image Classification Based on Hierarchical Visual Codebook," IEEE Transactions on Pattern Analysis and Machine Intelligence (T-PAMI), Vol. 36, No. 6, pp.1120-1133, 2014.
#### **Iris Liveness Detection: A Sensor Solution**







Microlens array Image sensor

Fake



Light-field Camera (Plenoptic Camera)



Depth perception

image regions around human eyes

Focus value variations of refocused





Liveness detection



# **Iris Liveness Detection Using Light Field Cameras**

Analysis on light field focal stack and the all-in-focus image for iris liveness detection



Ping Song, Ling Huang, Yunlong Wang, Fei Liu, Zhenan Sun. Iris Liveness Detection Based on Light Field Imaging, IEEE/CAA Journal of Automatica Sinica (**JAS**), vol.45, no.9, pp.1701-1712, 2019.

### **Other Possible Ways for Iris Liveness Detection**



- **1. Spectrographic and stereoscopic properties of eyes**
- 2. Specular reflections caused light spots
- 3. Eyelid movement
- 4. Challenge-response
- 5. Facial features, head movement, body sway, etc.
- 6. Multi-biometrics



# **Iris Image Quality Assessment**



Occlusions

# Iris Image Quality Assessment based on Fusion of Individual Quality Metrics (3Q Model)



X. Li, Z. Sun, T. Tan, Comprehensive assessment of iris image quality, ICIP2011.

# **Recognition Oriented Iris Image Quality Assessment**

Qualified iris images are selected from video sequences based on their potential contributions to recognition accuracy, rather than the subjective factors such as visual appearance.



- Distance to high-quality iris images in Feature Space (DFS) is used as the ground-truth quality metric
- Prediction of iris quality score is based on deep neural networks with the attention mechanism
  - More iris images are possibly selected for recognition

Leyuan Wang, Kunbo Zhang, Min Ren, Yunlong Wang, Zhenan Sun, "Recognition Oriented Iris Image Quality Assessment in the Feature Space," IEEE International Joint Conference on Biometrics (*IJCB*), 2020.

# **Iris Localization and Segmentation**

- Iris localization and segmentation define the valid iris regions used for feature extraction and matching.
- The two problems are usually addressed separately.



#### **Typical Iris Localization Methods**

#### **Daugman's algorithm:** coarse to fine strategy



Daugman J. How iris recognition works[J]. IEEE Transactions on Circuits and Systems for Video Technology (*T-CSVT*), 2004, 14(1): 21-30.

#### **Typical Iris Localization Methods**





Wildes R P. Iris recognition: an emerging biometric technology[J]. Proceedings of the IEEE, 1997, 85(9): 1348-1363.

## **Iris Localization and Segmentation Methods**

#### **Region Based Methods**

Pixel classification (Proença, TPAMI'10) Pixel clustering (Tan, IVC'10) Local pixel dependencies (Kumar, TIP'12) Iterative thresholding (Gangwar, ICB'16)

#### **Edge Based Methods**

Integrodifferential operator (Daugman, TCSVT'04) Hough transform (Wildes, Proc. of IEEE'97) Active contours (Shah and Ross, TIFS'09) Pulling and pushing (He, Tan et al., TPAMI'09) Polar Spline RANSAC (Ruggero et al., CVIU'19)



### **Iris Segmentation Based on Deep Learning**

Mainly concentrating on predicting accurate iris masks by following popular semantic segmentation frameworks, e.g., FCN, Mask R-CNN, U-Net, Densenet, Hourglass network

![](_page_46_Figure_2.jpeg)

## **Problems of the Existing Methods**

Deep learning has been successfully used for iris segmentation, but the segmentation result lacks of iris boundary information for iris normalization.

![](_page_47_Picture_2.jpeg)

#### **Our Solution: Simultaneous Iris Segmentation and Localization**

We proposed a unified framework for simultaneously learning segmentation mask and inner/outer iris boundaries, followed by simple yet efficient post-processing operations for complete iris segmentation.

![](_page_48_Figure_2.jpeg)

Caiyong Wang, Jawad Muhammad, Yunlong Wang, Zhaofeng He and Zhenan Sun, "Towards Complete and Accurate Iris Segmentation Using Deep Multi-task Attention Network for Non-Cooperative Iris Recognition," IEEE Transactions on Information Forensics and Security (*TIFS*), 2020, vol. 15, pp. 2944-2959, 2020.

#### **Experimental Results of Joint Iris Segmentation and Localization**

-	-		$\bigcirc$		-		Method	Database	<i>E</i> 1	<i>E</i> 2	<b>F</b> 1
Mr. And	Hennes	Mr. Ander							(%)	(%)	(%)
TRE	-		$\circ$		-0-		T. Tan <i>et al.</i> [90]	UBIRIS.v2 (NICE.I)	1.31	N/A	N/A
1	1	1			2/2			CASIA.v4-distance	0.68	0.44	87.55
0			$\bigcirc$	•			RTV- <i>L</i> <sup>1</sup> [92]	UBIRIS.v2 (NICE.I)	1.21	0.83	85.97
								MICHE-I	2.42	1.21	79.24
1	0	0			0		Haindl and	UBIRIS.v2 (NICE.I)	3.24	1.62	77.03
			$\bigcirc$				Krupička [93]	MICHE-I	3.86	1.93	70.17
10	10	10	$\bigcirc$				MFCNs [101]	CASIA.v4-distance	0.59	0.24	93.09
								UBIRIS.v2 (NICE.I)	0.90	0.49	91.04
			$\bigcirc$					MICHE-I	0.74	0.37	92.01
		$\overline{\circ}$	$\bigcirc$	•			CNNHT [2] (RefineNet)	CASIA.v4-distance	0.56	0.28	92.27
CREATION OF THE OWNER		State Construction of Construction	$\bigcirc$					UBIRIS.v2 (NICE.I)	0.97	0.48	90.34
Con the	0	0.	$\bigcirc$					MICHE-I	0.80	0.40	91.41
C			0				IrisParseNet	CASIA.v4-distance	0.41	0.20	94.25
								UBIRIS.v2 (NICE.I)	0.84	0.42	91.78
							MICHE-I	0.66	0.33	93.05	
(a) Iris image	(b) Ground truth	(c) Iris Segmentation	(d) Iris outer bo	undary (e) Pupil ma	ask (f) Localization	n					

#### **Nonlinear Iris Deformation**

![](_page_50_Picture_1.jpeg)

# **Iris Normalization**

Higher iris recognition accuracy can be achieved using nonlinear iris normalization methods

![](_page_51_Picture_2.jpeg)

Nonlinear **Piecewise-linear** Linear

	EER	Discri Index	Time (s)
Linear	1.0585%	4.7094	0.0862
Nonlinear	0.85067%	4.9913	0.0693

![](_page_51_Figure_5.jpeg)

Linear mapping model:  $f(x) = \frac{R}{r}x$ 

**Piecewise-linear mapping model:** 

$$f(x) = \begin{cases} \frac{nkR + (1-k)(R-r)}{nkr} x & x \in [0, kr] \\ \frac{R-r}{n} + \frac{nR - (R-r)}{nr} x & x \in (kr, r] \end{cases}$$

Nonlinear mapping:

 $f(x) = \frac{R - br}{\ln(ar + 1)} \ln(ax + 1) + bx$ 

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#### **Flowchart of Iris Recognition**

![](_page_53_Picture_1.jpeg)

## **Objective of Iris Pattern Representation**

![](_page_54_Picture_1.jpeg)

Minimize intra-class distance and maximize inter-class distance

#### **Iris Pattern Representation**

![](_page_55_Figure_1.jpeg)

## **Daugman's Method: IrisCode**

![](_page_56_Figure_1.jpeg)

J. Daugman, High confidence visual recognition of persons by a test of statistical independence, IEEE Trans. on Pattern Analysis and Machine Intelligence (*T-PAMI*), vol.15, no.11, pp.1148-1161, 1993.

#### **Examples of IrisCodes**

![](_page_57_Picture_1.jpeg)

#### **Distribution of Hamming Distances and Decision**

![](_page_58_Figure_1.jpeg)

#### **Two Important Questions in Iris Recognition**

Why do some iris recognition algorithms perform better (e.g., why is Daugman's lrisCode so good)?

How to do better than the best (e.g., can we possibly outperform Daugman's IrisCode)?

#### **Ordinal Measures for Iris Pattern Recognition**

![](_page_60_Figure_1.jpeg)

Zhenan Sun and Tieniu Tan, "Ordinal Measures for Iris Recognition", IEEE Transactions on Pattern Analysis and Machine Intelligence (*T-PAMI*), Vol. 31, No. 12, 2009, pp. 2211 - 2226.

## **Ordinal Measures for Iris Pattern Recognition**

![](_page_61_Figure_1.jpeg)

Zhenan Sun and Tieniu Tan, "Ordinal Measures for Iris Recognition", IEEE Transactions on Pattern Analysis and Machine Intelligence (*T-PAMI*), Vol. 31, No. 12, 2009, pp. 2211 - 2226.

#### **Ordinal Measures for Iris Pattern Recognition**

![](_page_62_Figure_1.jpeg)

**High accuracy and low computational cost** 

Zhenan Sun and Tieniu Tan, "Ordinal Measures for Iris Recognition", IEEE Transactions on Pattern Analysis and Machine Intelligence (*T-PAMI*), Vol. 31, No. 12, 2009, pp. 2211 - 2226.

#### **Ordinal Measures Extended to Face and Palmprint Recognition**

![](_page_63_Figure_1.jpeg)

Ordinal feature selection for palmprint recognition

Libin Wang, Zhenan Sun and Tieniu Tan, "Ordinal Feature Selection for Iris and Palmprint Recognition", IEEE Transactions on Image Processing (*TIP*), Vol. 23, No. 9, 2014, pp.3922-3934.

Ran He, Tieniu Tan, Larry Davis, Zhenan Sun, "Learning structured ordinal measures for video based face recognition", Pattern Recognition (*PR*), Vol. 75, 2018, pp.4-14.

#### **Light CNN for Face Recognition Inspired by Ordinal Measures**

![](_page_64_Figure_1.jpeg)

Xiang Wu, Ran He, Zhenan Sun, Tieniu Tan, "A Light CNN for Deep Face Representation with Noisy Labels", IEEE Trans. on Information Forensics and Security (*TIFS*), Vol.13, No.11, 2018, pp.2884-2896.

# **Uncertainty Learning in Iris Recognition**

Interfering or uncertain factors always exist during iris image acquisition. This means that an iris image should ideally be represented using a probabilistic distribution rather than a deterministic point in the feature space.

![](_page_65_Figure_2.jpeg)

# Learning Uncertainty Embedding for Iris Recognition

Uncertainty embedding is proposed to generate a discriminative and robust iris representation

![](_page_66_Figure_2.jpeg)

Jianze Wei, et al., Towards More Discriminative and Robust Iris Recognition by Learning Uncertain Factors, IEEE Transactions on Information Forensics and Security (*TIFS*), vol. 17, pp. 865-879, 2022.

#### **The Occlusion Problem in Biometrics**

![](_page_67_Picture_1.jpeg)

# **Dynamic Graph Representation for Iris Recognition**

- Modelling both local features and geometric relationships between local regions using deep graphical models
- The nodes of the occluded parts are removed during matching
- Robust against occlusions in iris recognition, face recognition and person ReID tasks

![](_page_68_Figure_4.jpeg)

Min Ren, et al., "Dynamic Graph Representation for Occlusion Handling in Biometrics," Thirty-Fourth AAAI Conference on Artificial Intelligence (*AAAI*), 2020.

Min Ren, et al., "Multiscale Dynamic Graph Representation for Biometric Recognition with Occlusions," IEEE Transactions on Pattern Analysis and Machine Intelligence (*T-PAMI*), 2022, minor revision.

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## **Applications of Iris Recognition**

![](_page_70_Picture_1.jpeg)

Coal miner attendance

![](_page_70_Picture_3.jpeg)

Banking

![](_page_70_Picture_5.jpeg)

Mobile payment

![](_page_70_Picture_7.jpeg)

**Public Security** 

![](_page_70_Picture_9.jpeg)

Border control

![](_page_70_Picture_11.jpeg)

Social welfare

![](_page_70_Picture_13.jpeg)

Missing children identification

![](_page_70_Picture_15.jpeg)

Pet care

## **Iris Recognition for Social Welfare**

Our iris recognition technology has helped more than 3 million refugees in the middle east receive WFP (World Food Programme) and UNHCR (United Nations High Commissioner for Refugees) supplies.

![](_page_71_Picture_2.jpeg)

Syrian Arab Republic

6 October 2016

WFP Introduces Iris Scan Technology To Provide Food Assistance To Syrian Refugees In Zaatari

![](_page_71_Picture_5.jpeg)

(Innovation Service

Using biometrics to bring assistance to refugees in Jordan

![](_page_71_Picture_8.jpeg)

![](_page_71_Picture_9.jpeg)

![](_page_71_Picture_10.jpeg)

![](_page_71_Picture_11.jpeg)
# **Iris Recognition for Social Welfare**



# **Iris Recognition for Coal Miner Identification**





Our technology has been in routine use in many coal mines across China.

# **Iris Recognition for Animal Identification**



# **Iris Recognition of Dogs**



Special portable iris devices are developed to capture more than 40,000 images of 2,000 dogs.





# **Iris Recognition of Dogs**



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VS

1. Constraints on users during iris image acquisition





Varying real world scenarios (user, illumination, etc.)



Fixed optics settings of iris sensors

### 2. Deteriorated performance on poor quality iris images



### 3. Recognition of heterogenous iris images



Surveillance



Mobile





Internet



Iris at a distance







4. Unpredictable iris spoof attacks

VS



Examples of training samples. (a)-(f): Contact lens wearing iris images. (g) Printed iris. (h) Glass eye. (i)-(l): Live iris images.

#### Limited training data



#### Unpredictable iris spoof attacks

5. Category fairness (Ethnic generalizability)



CASIA-Iris-Lamp and Distance



Dataset	EER	FNMR@FMR		
		10%	0.1%	0.001%
CASIA-Iris-Africa	1.07%	0.35%	49.48%	99.94%
CASIA-Iris-Distance	0.60%	0.10%	1.17%	5.55%
CASIA-Iris-Lamp	1.85%	0.94%	3.53%	6.88%



• High-throughput iris recognition in unconstrained environments Simultaneous iris recognition of multiple people at a distance within seconds



## Co-design and coordination of iris sensing and recognition



Imaging control signal (focal lens, aperture, exposure...)

Hardware-software co-design

Acquisition and processing coordination

• Device-agnostic cloud service for heterogenous iris recognition





• Human-centric sensing and adaptive multi-biometrics fusion



• Privacy and security preserving decentralized applications



Distributed applications facing a diversity of users, devices and environments Federated learning inspired multi-client cooperation

# Future Directions of Iris Recognition Iris recognition for Metaverse and VR/AR/MR



## **Roadmap of Iris Recognition**





#### Ways forward:

- Number of subjects: 1 to N
- Imaging distance: close- to long-range
- State of subject: static to moving
- Environment: indoor to outdoor
- Modality: single to multi-modality
- Security and Privacy: centralized to decentralized

All in focus

Innovations in both sensors and algorithms are needed to achieve less constraining and high throughput iris recognition.

# Conclusions

- Great progress on iris recognition has been made in the past decades.
- State-of-the-art iris recognition technologies are good enough for many practical applications.
- Much remains to be done to develop more userfriendly and robust iris recognition solutions.

# Small Iris, Big Topic, Great Future!



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# Thank You!