中国科学院
自动化研究所
INSTITUTE OF AUTOMATION
CHINESE ACADEMY OF SCIENCES

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Iris Recognition: Fundamentals, Progress and Challenges

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January 8, 2023

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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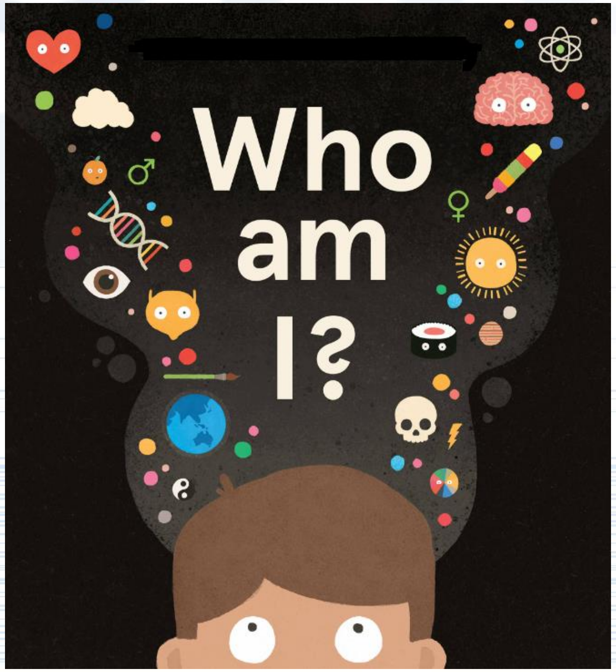
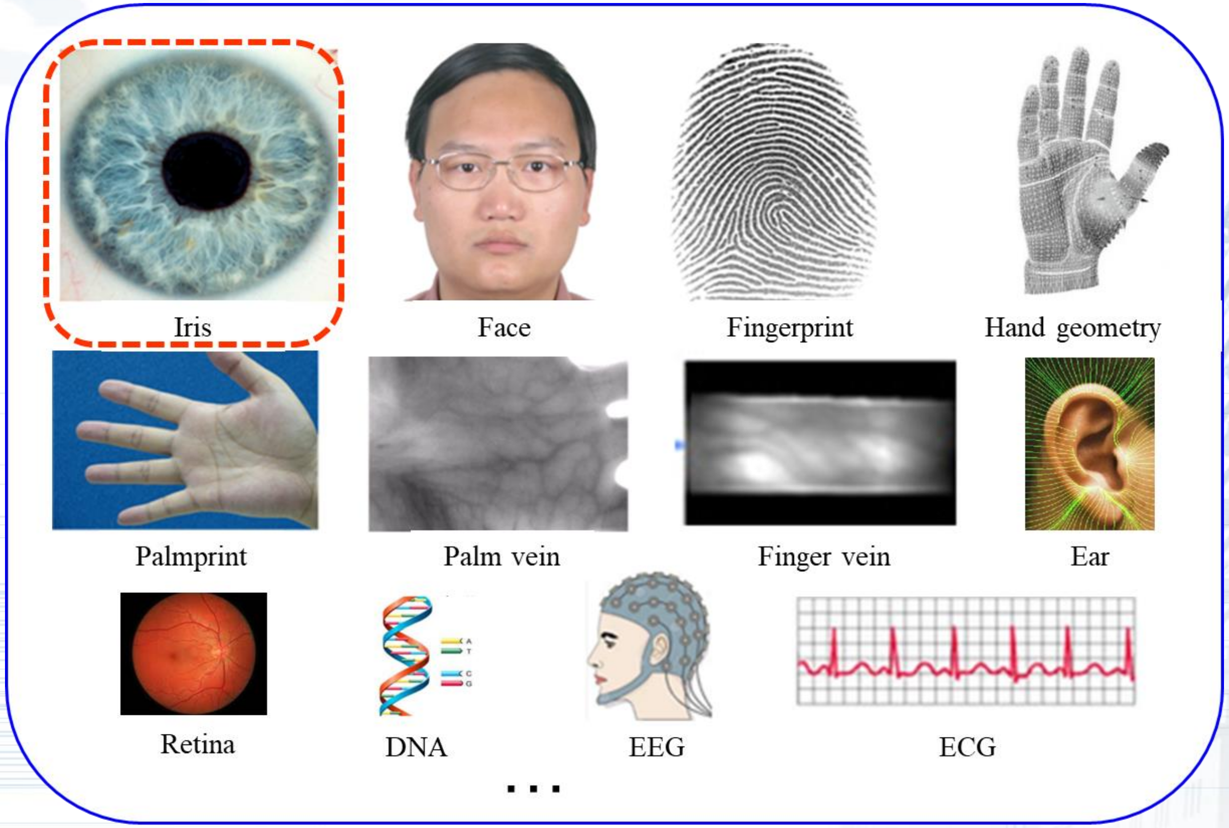
Iris in the Context of Biometrics



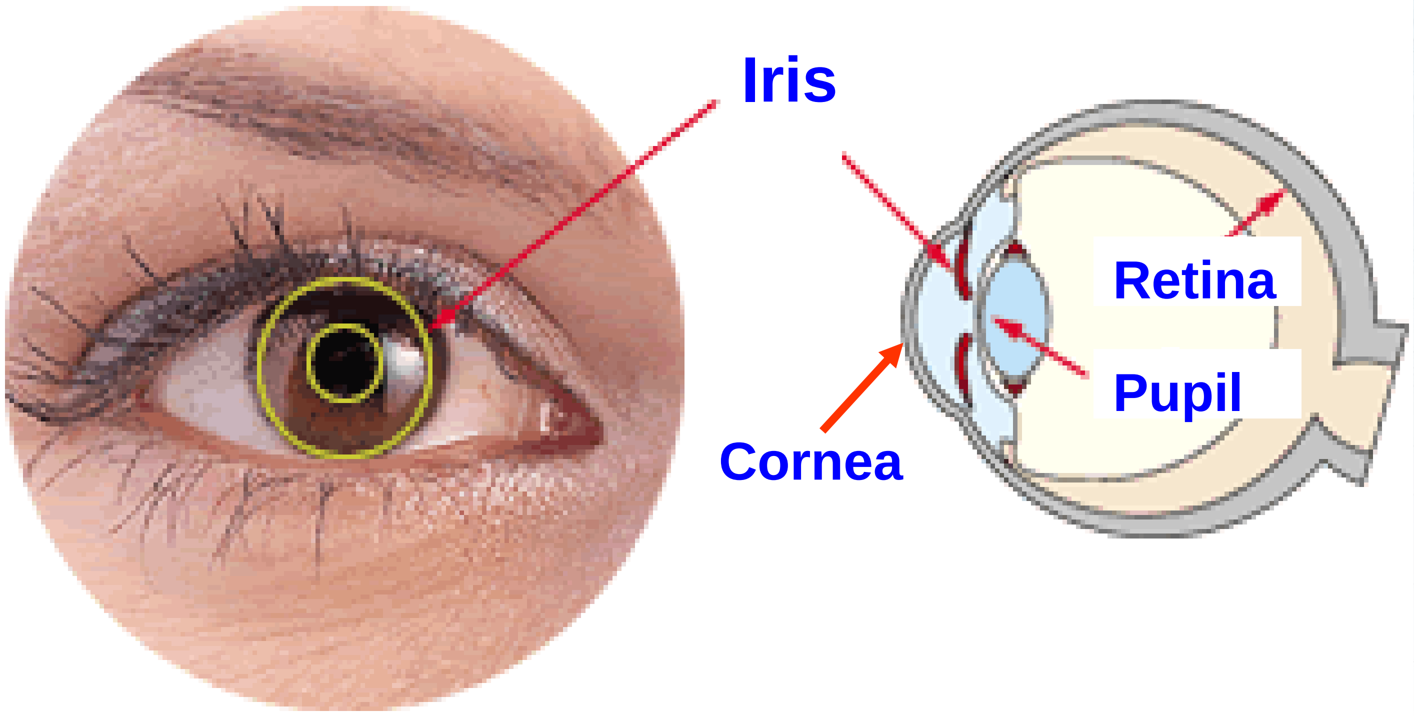


Biological Traits

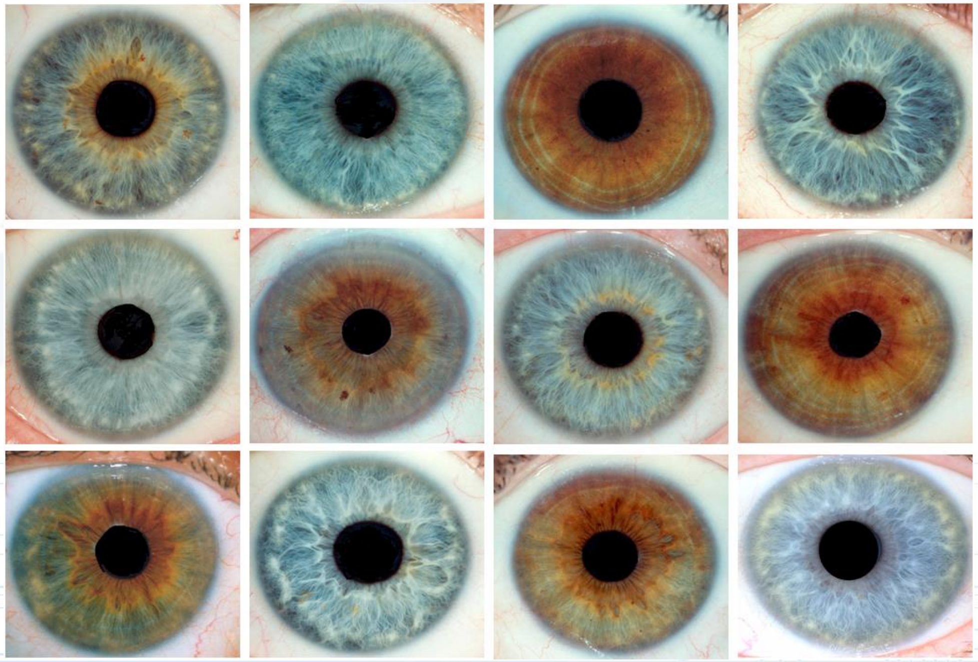
Behavioral Traits

Human Iris

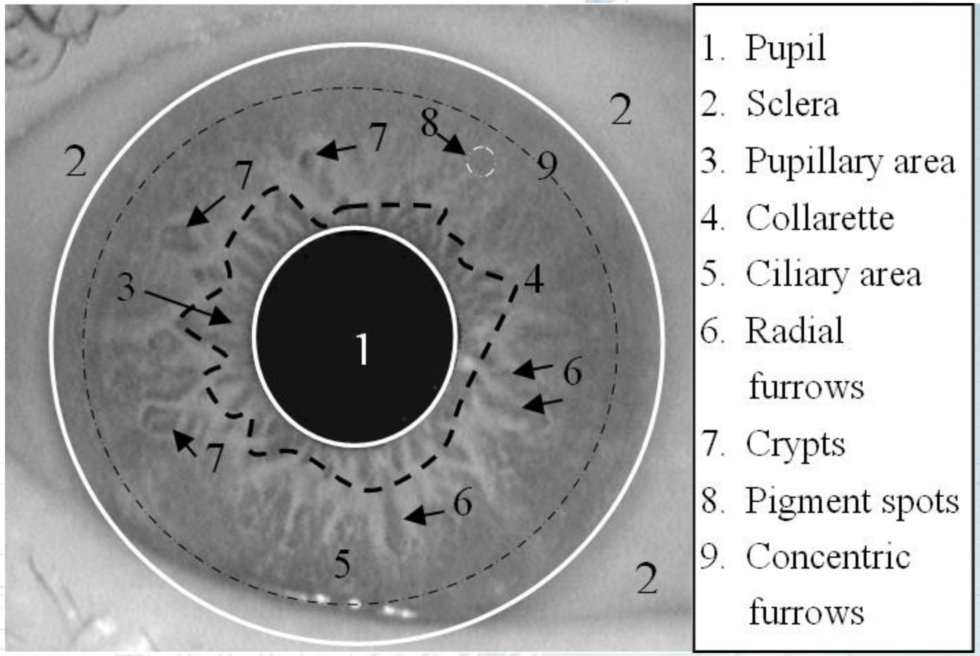
- Iris is the ring-shaped colored membrane between the pupil and the sclera
- Protected by cornea but externally visible
- Highly textured



Iris Textures under Different Illumination



Visible illumination

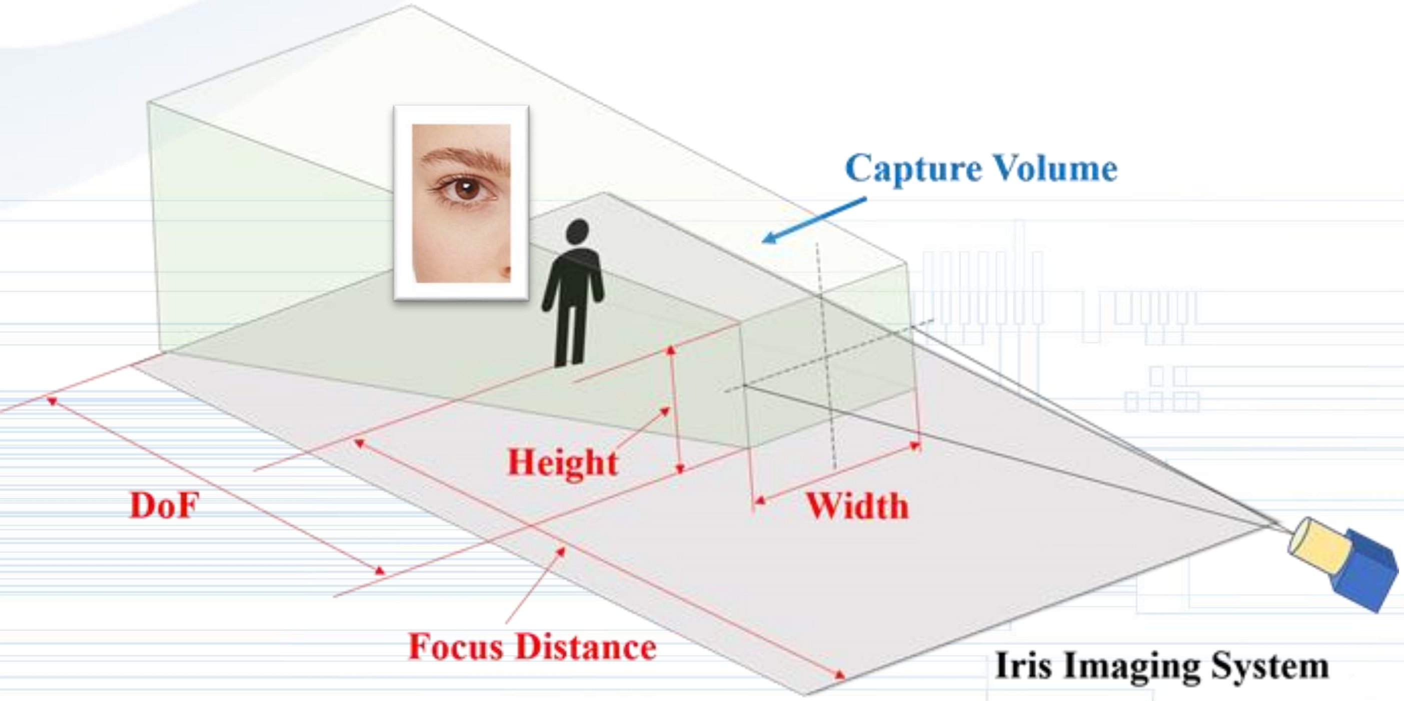


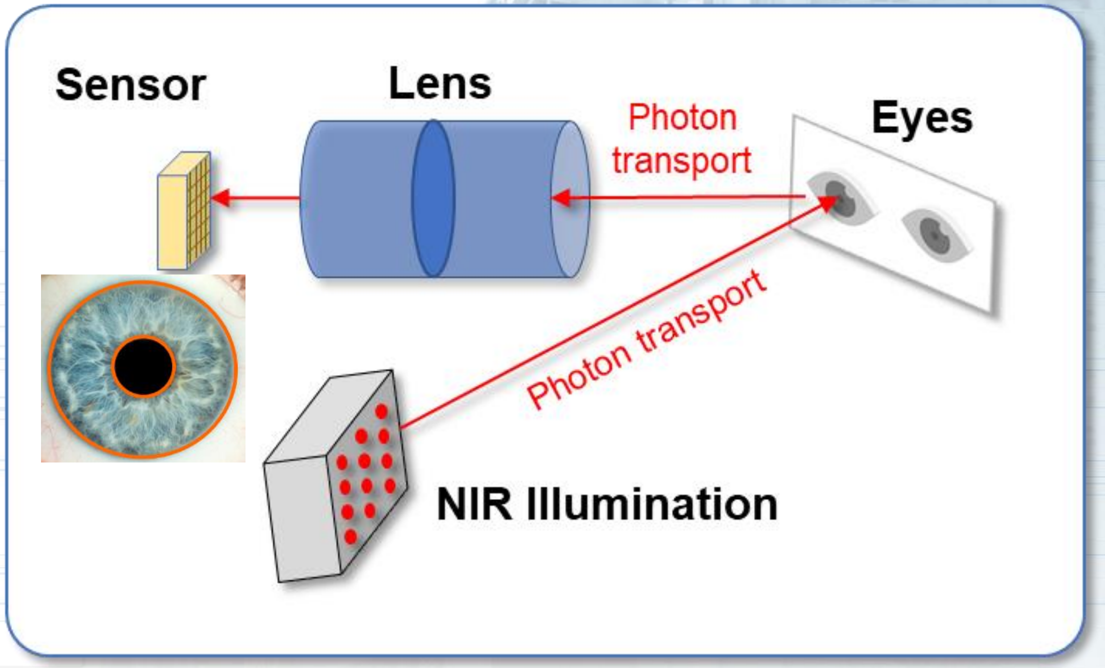
Near infrared illumination

- 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

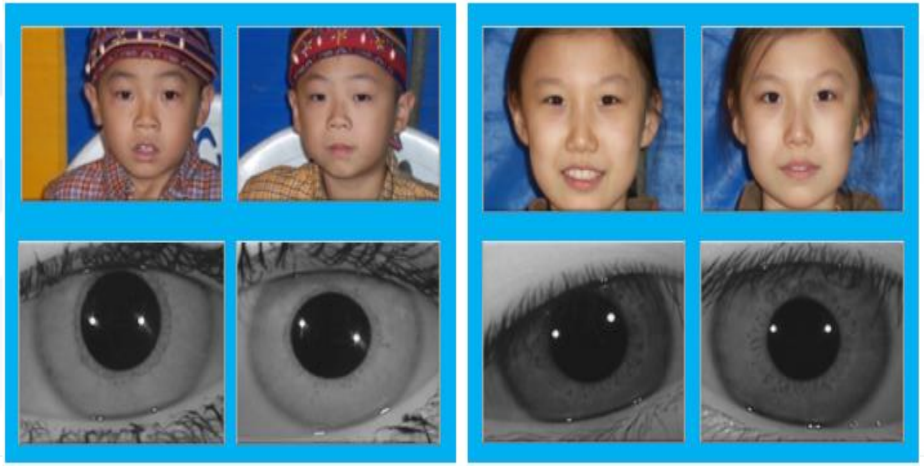
Iris Recognition

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

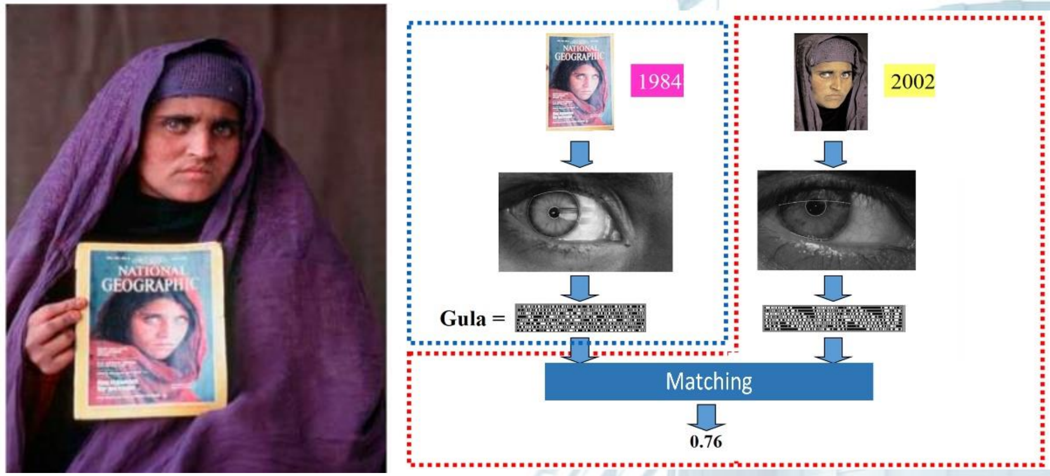




Why Iris Recognition?

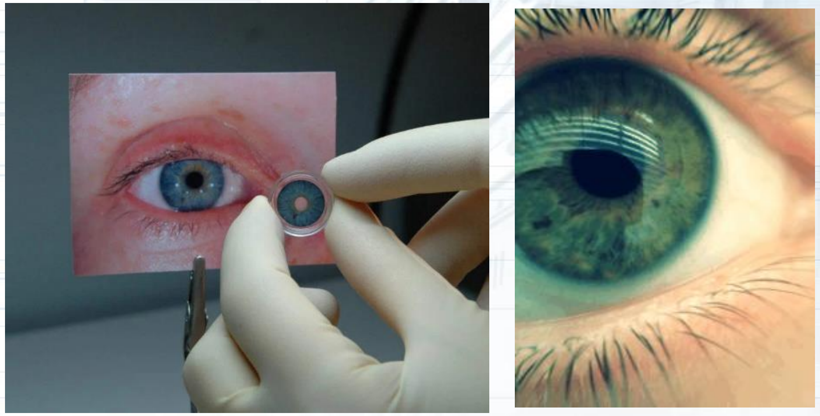


Unique



Stable

Non-intrusive



Hard to fake

Why Iris Recognition?

Comparison with Other Biometric Modalities

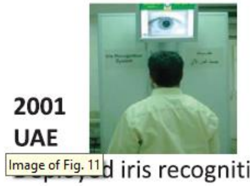
Biometrics	Universality	Uniqueness	Stability	Collectability	Accuracy	Acceptability	Security
Face	High	Low	Medium	High	Low	High	Low
Fingerprint	Medium	High	High	Medium	High	Medium	High
Hand	Medium	Medium	Medium	High	Medium	Medium	Medium
Vein	Medium	Medium	Medium	Medium	Medium	Medium	High
Iris	**High**	**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

1936
Frank Burch
Concept of using iris patterns for human identification

1985
Flom and Safir
First iris recognition patent

1991
John Daugman
Iris recognition patent

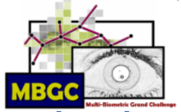


2001
UAE
Deployed iris recognition system for border control

2002
USA
Use of iris recognition in field operations

2003
Immigration clearance at Schiphol airport

2009
India
Aadhaar



2010
Mexico
National ID

2011
Indonesia
National ID

2011
John Daugman
Patent expired

1989
John Daugman
First iris camera

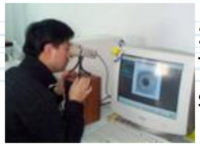
1995
IrisScanner System
One of the earliest commercial iris cameras

2004
SecuriMetrics
Portable iris recognition device

2006
Sarnoff
Iris on the Move

2013
AOptix
App & device for smartphone to capture iris

2013
DeltaID



1999 CASIA
The first iris recognition system in China

2006 NIST
Iris Challenge Evaluation (ICE)

2009 CASIA
Iris recognition at a distance (3m)

2015 IrisKing
Iris recognition on smartphones

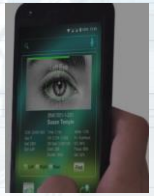
2017 WFP
Identify food assistance entitlement using iris recognition

2019 NEC
walkthrough iris recognition

2021 CASIA
Multi-person NIR iris recognition at a distance (10m)

2016 IriStar
Long-range iris and face recognition

2018 IrisGuard
EyePay® Mobile Phone

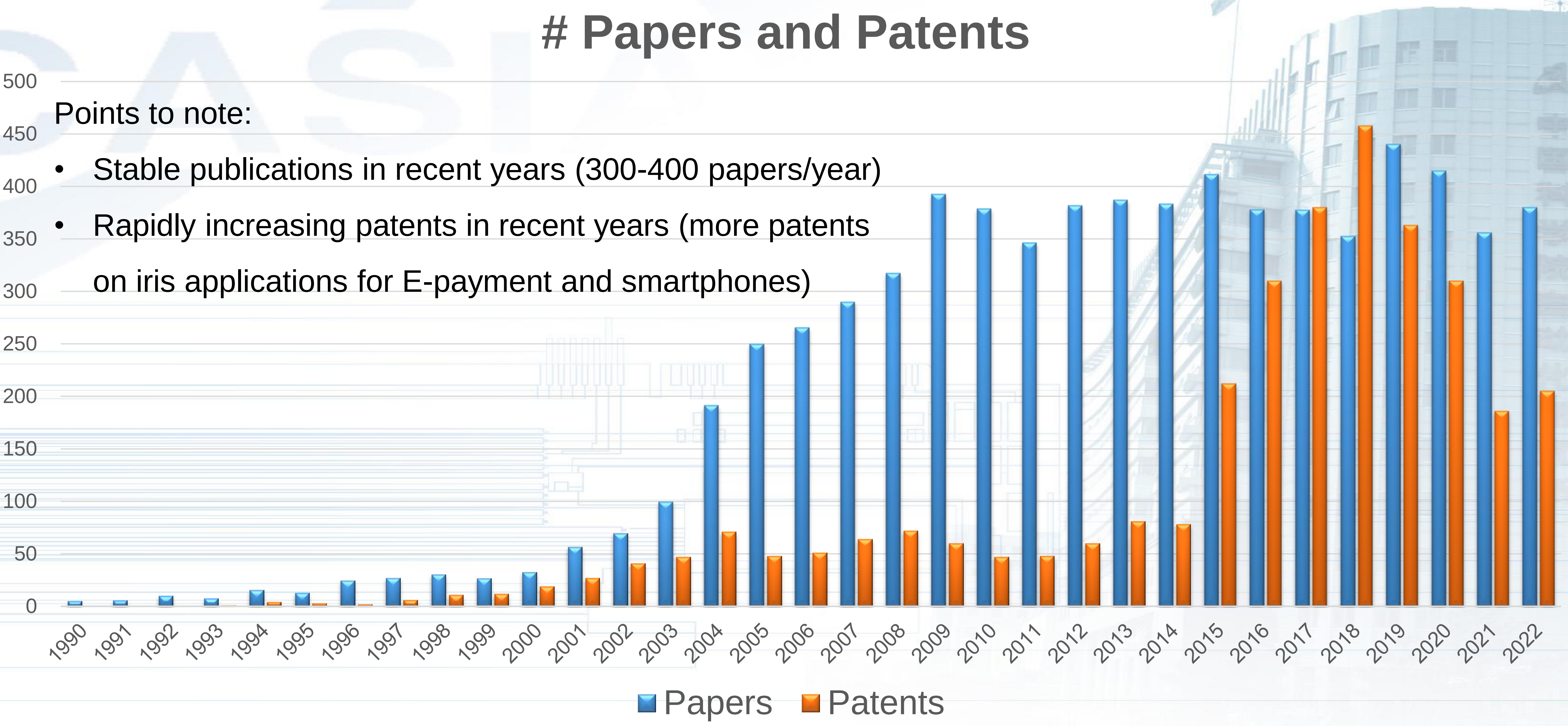


2020 IIIT-B MOSIP
An open source platform building national foundational IDs

MOSIP

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



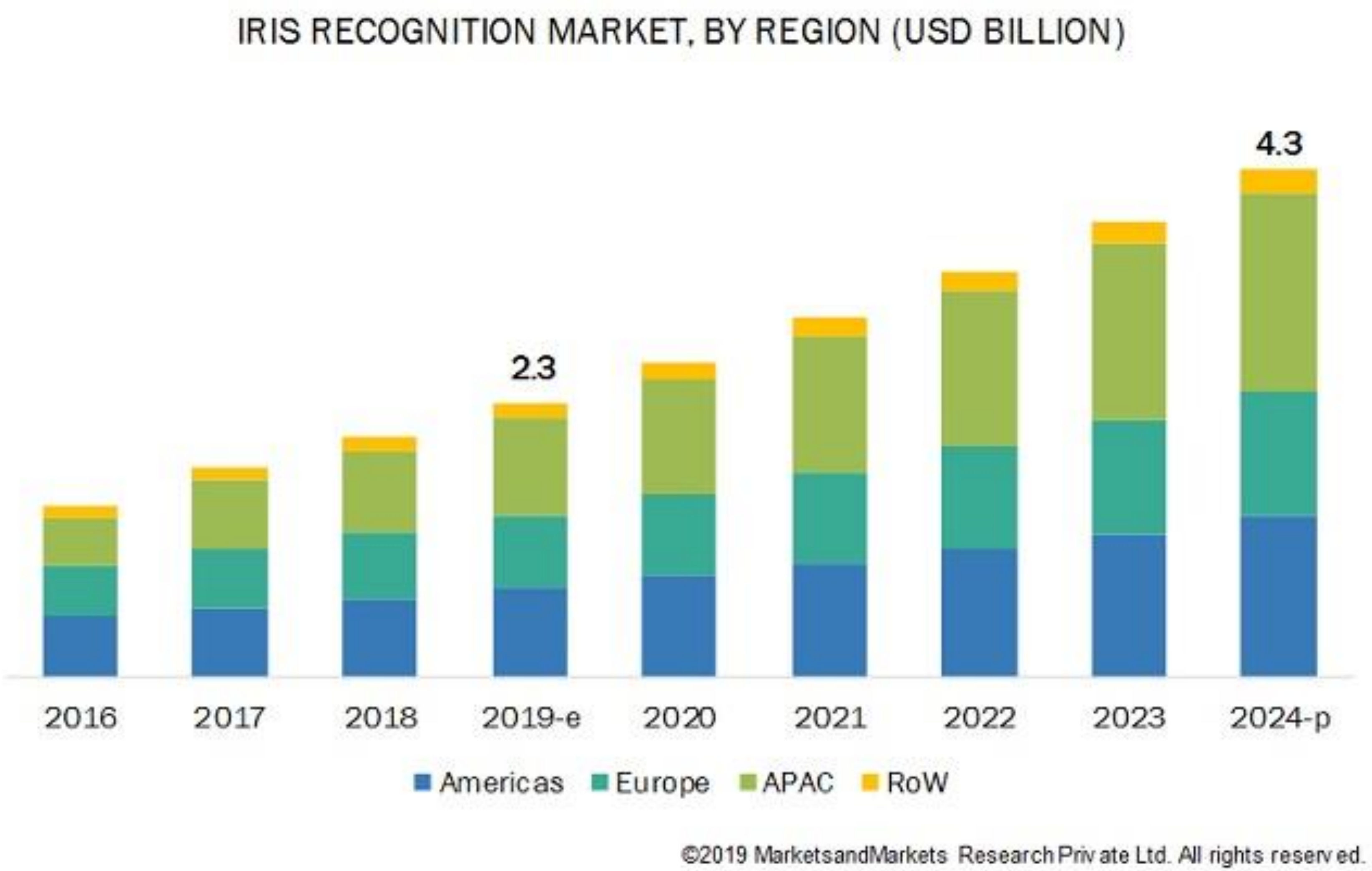
Points to note:

- Stable publications in recent years (300-400 papers/year)
- Rapidly increasing patents in recent years (more patents on iris applications for E-payment and smartphones)

Market Potential of Iris Recognition

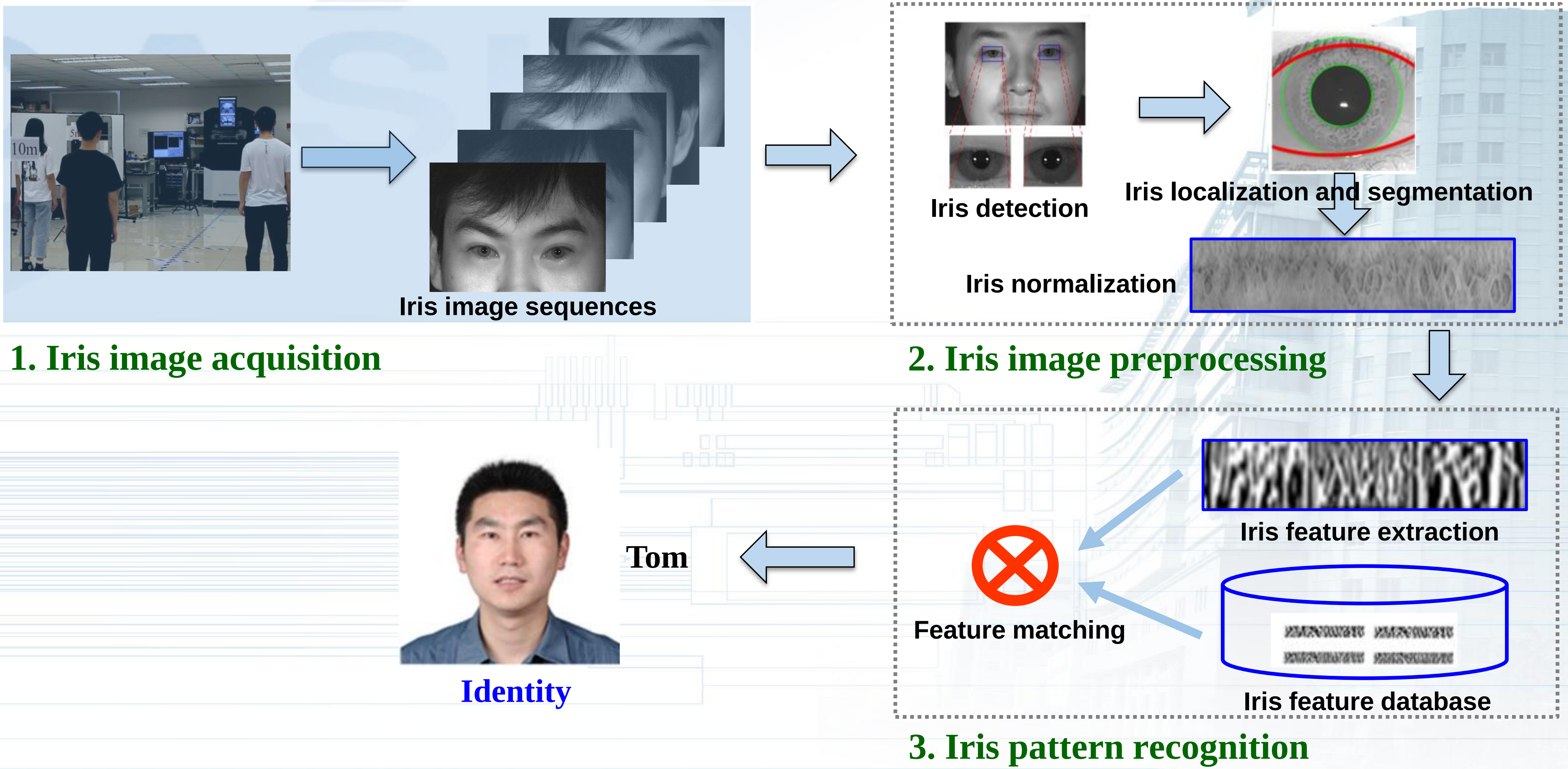
Points to note:

- 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.



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

Flowchart of Iris Recognition



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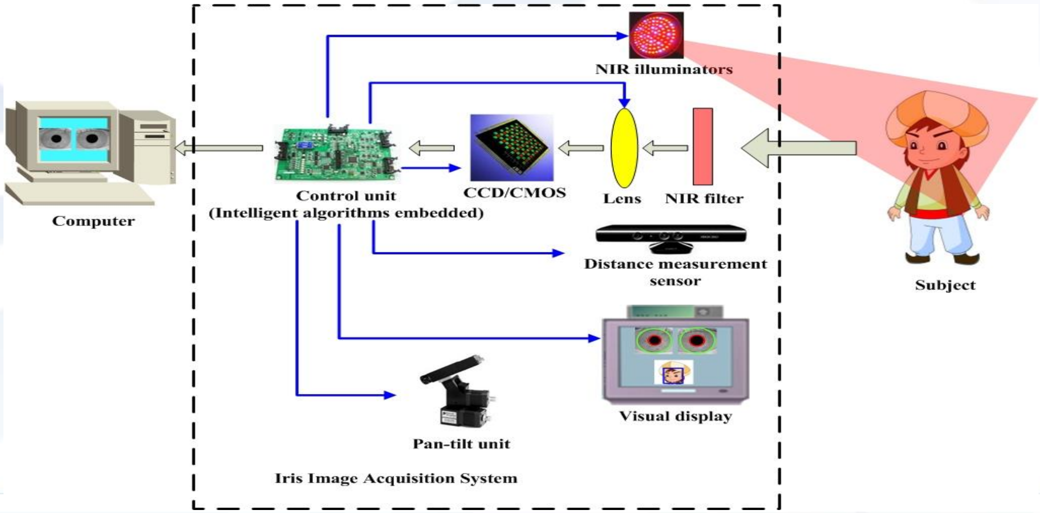
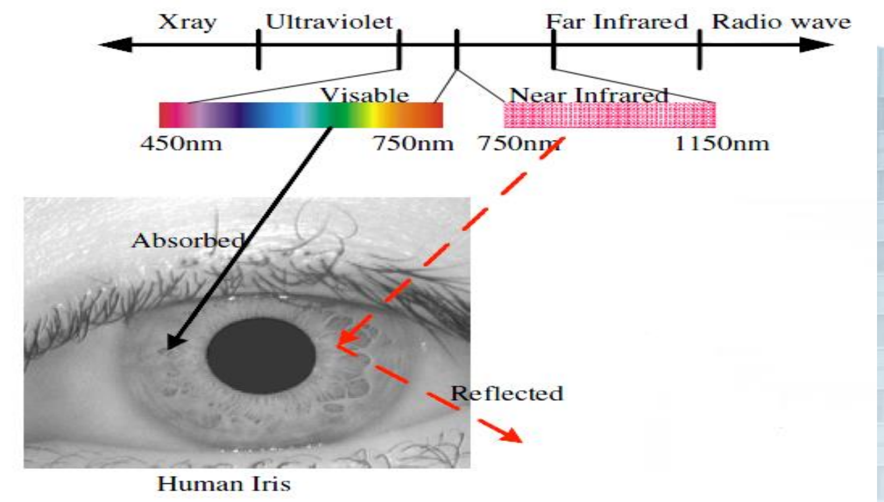
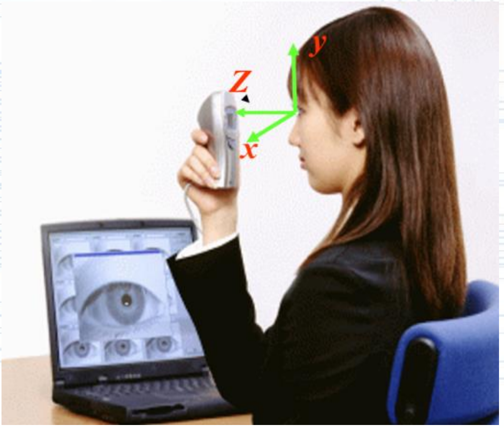
Iris Image Acquisition



Non-trivial Problem



Near-Infrared Illumination



Limited Depth of Field

VS

Variations in Location/Pose/Motion/Gaze

Close-range Iris Sensors


OKI Iris Pass-H


OKI Iris Pass-M


IrisID iCAM T10


IrisID iCAM 7000

IrisGuard EyeCash


Eyelock NANO iXT


IrisID iCAM TD100

HID Crossmatch I Scan 3


Panasonic BM-ET300


Panasonic BM-ET500


IrisGuard IG-H100


IrisGuard IG-AD100

IDEMIA OneLook

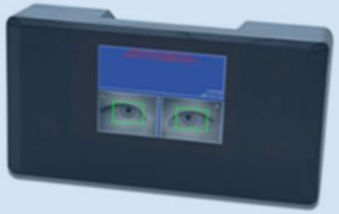

IrisKing IKAI1000


IrisKing IKUSB600


IrisKing IrisLock


SecuriMetrics PIER 2.3


HID Crossmatch I SCAN2


IrisKing IKEMB-110


IriTech IriShield BK 2121U


IrisKing IR400

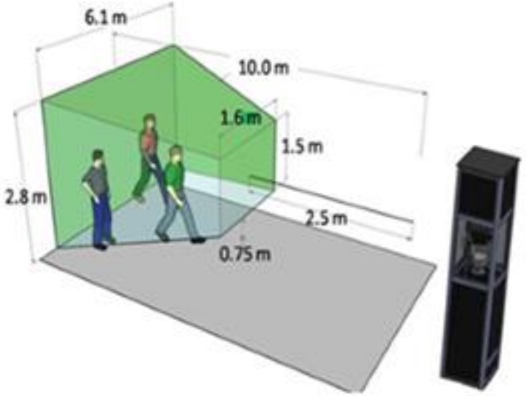
IrisStar S320-T1


IrisStar S300-UC

Long-range Iris Sensors

Aoptix Insight

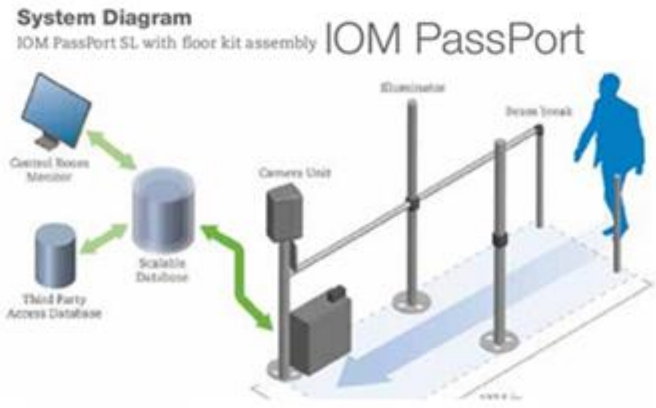
EyeLock HBOX



Eagle-eyes

IriStar S260P

IOM PassThru



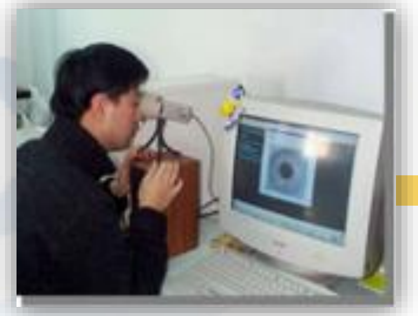
IOM Passport

IrisID iCAM D1000

IriStar S210G-S320G

IriStar S200P

Our Journey in Developing Iris Sensors


1999


2000


2001


2004


2005


2007


2008


2009

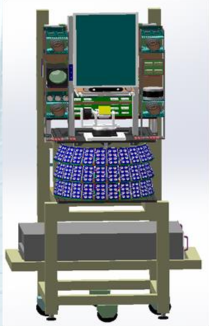

2014

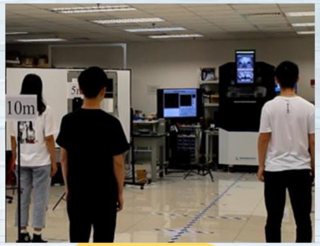

2015


2016


2018


2019

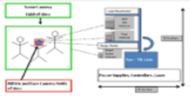




CASIA 10m Prototype
2021

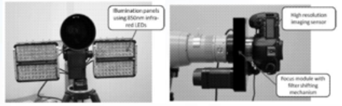
Limitations of the Existing Iris Sensors

2005 Sarnoff-Iris On the Move
2.4-3m, camera array, light gate, speed 1m/s

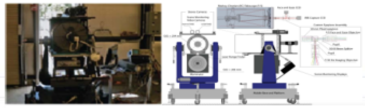


2008 Retica-Eagle-Eyes
3-6m, 3m x 2m x 3m capture volume, double cameras

2009 CASIA
2.4-3m, 0.15m x 0.15m x 0.1m, PTZ camera



2011 CMU
Up to 12m, 150 px, speed 0.6m/s



2013 SRI
25m, indoor & outdoor, 254mm diameter lens

2014 Iris ID-iCAM D1000
0.5-1m, 0.2m x 0.5m x 0.5m, Vertical moving camera

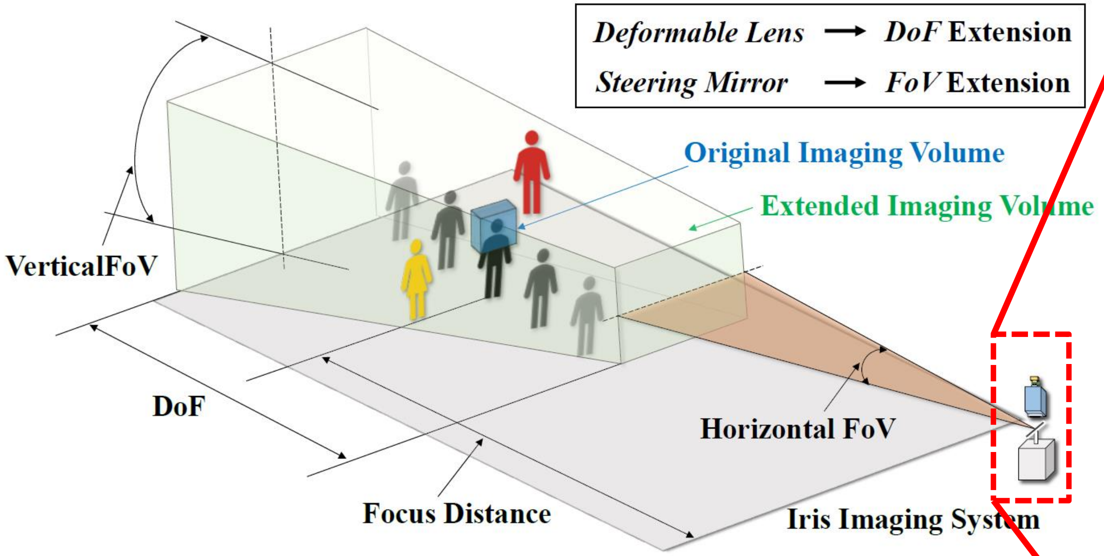
2017 Iristar S200P
1-1.2m, 1.3-1.95m height, ToF, face iris fusion

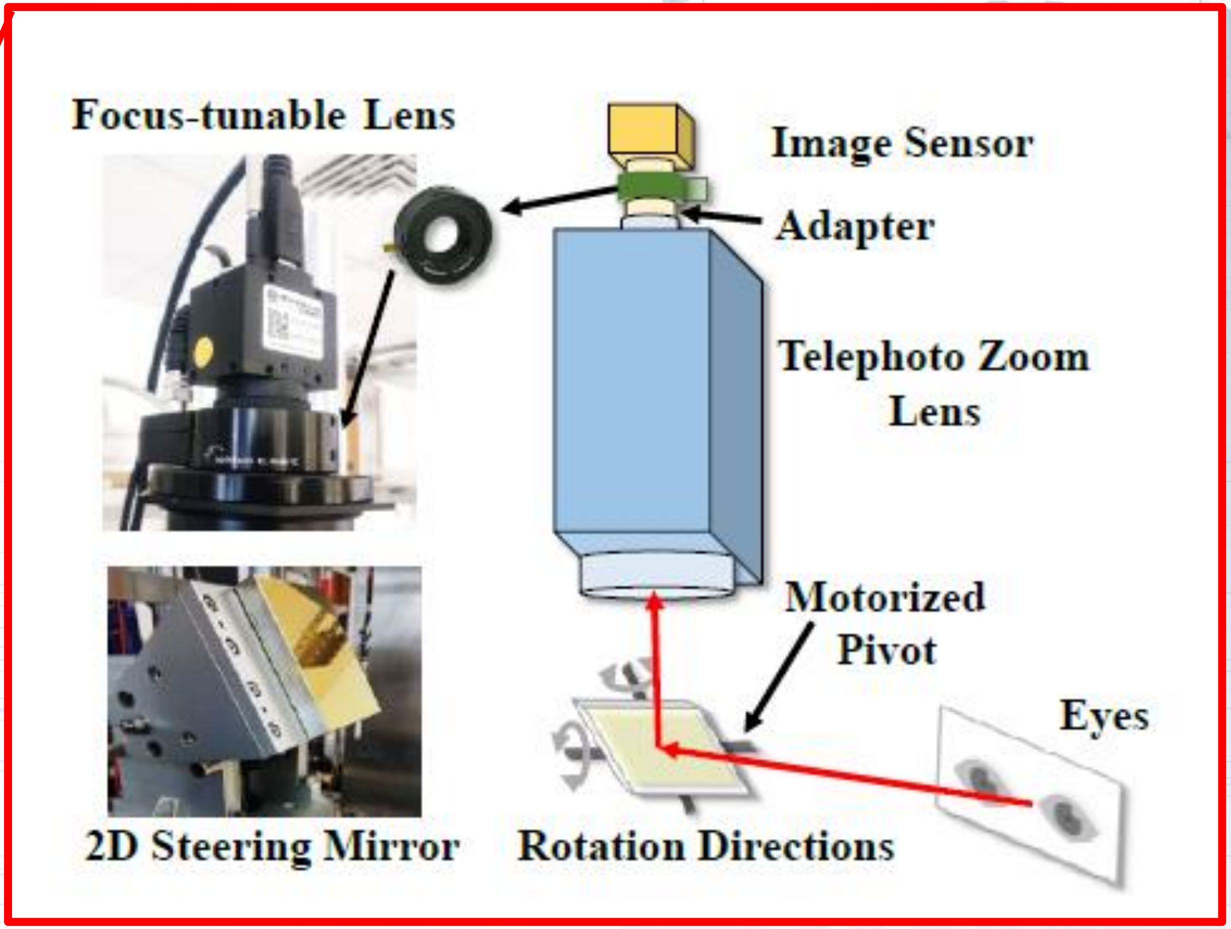
2020 Irisian VERSA F MAX
0.8-2m, PTZ camera, temperature measurement

- **Small capture volume**
- **Single person**
- **Bulky optical components**
- **Slow mechanical movement**
- **Fixed-focus**
- **Standstill capture**

➢ **Low throughput**
➢ **Poor user experience**

Iris Imaging With Expanded Capture Volume





Combining a two-axis beam steering mirror and focus-tunable lens integrated with a telephoto zoom lens

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

Multi-view multiplexing

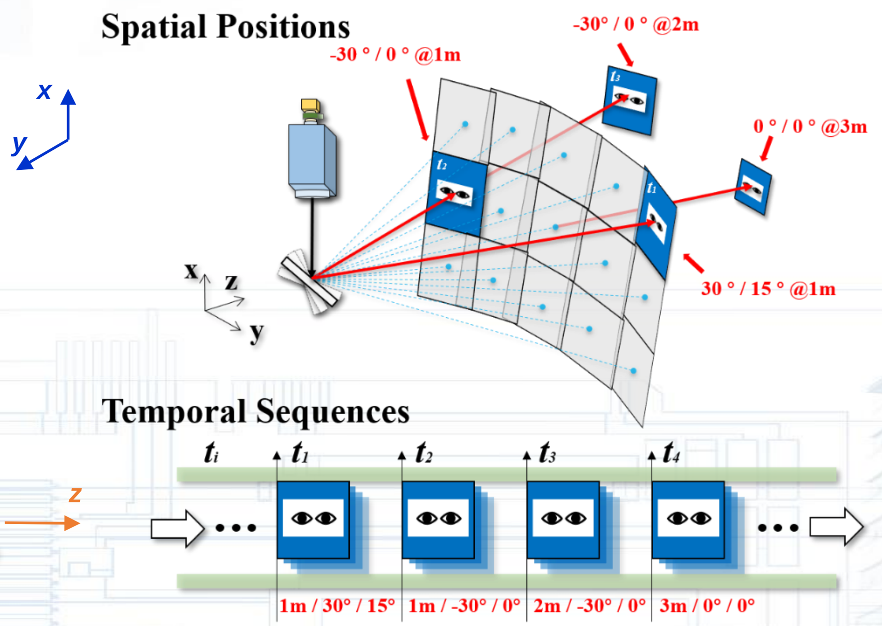
(FoV extension)

arc sec±10

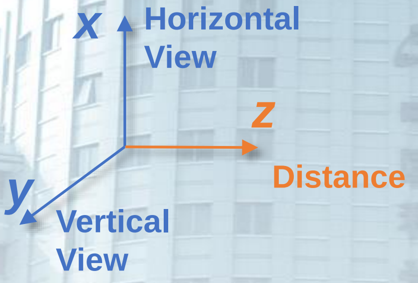
Multi-focus multiplexing

(DoF extension)

2.5 ms



Spatial-temporal multiplexing imaging

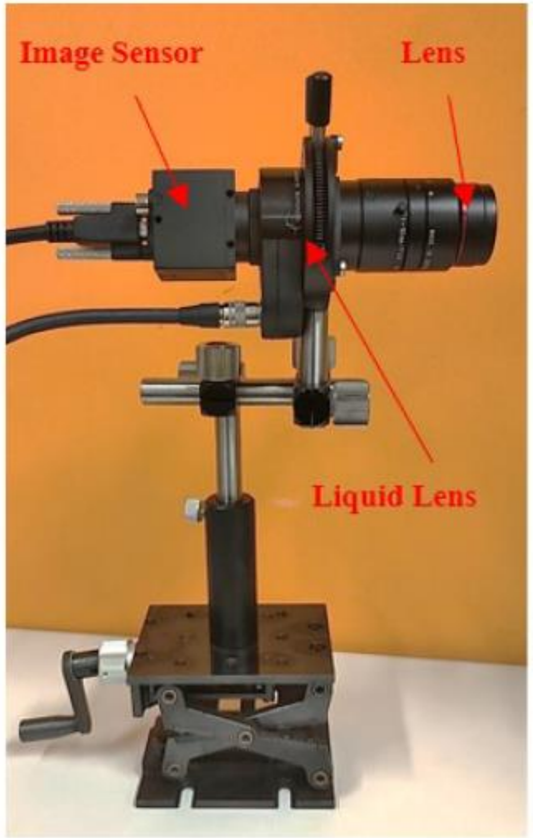


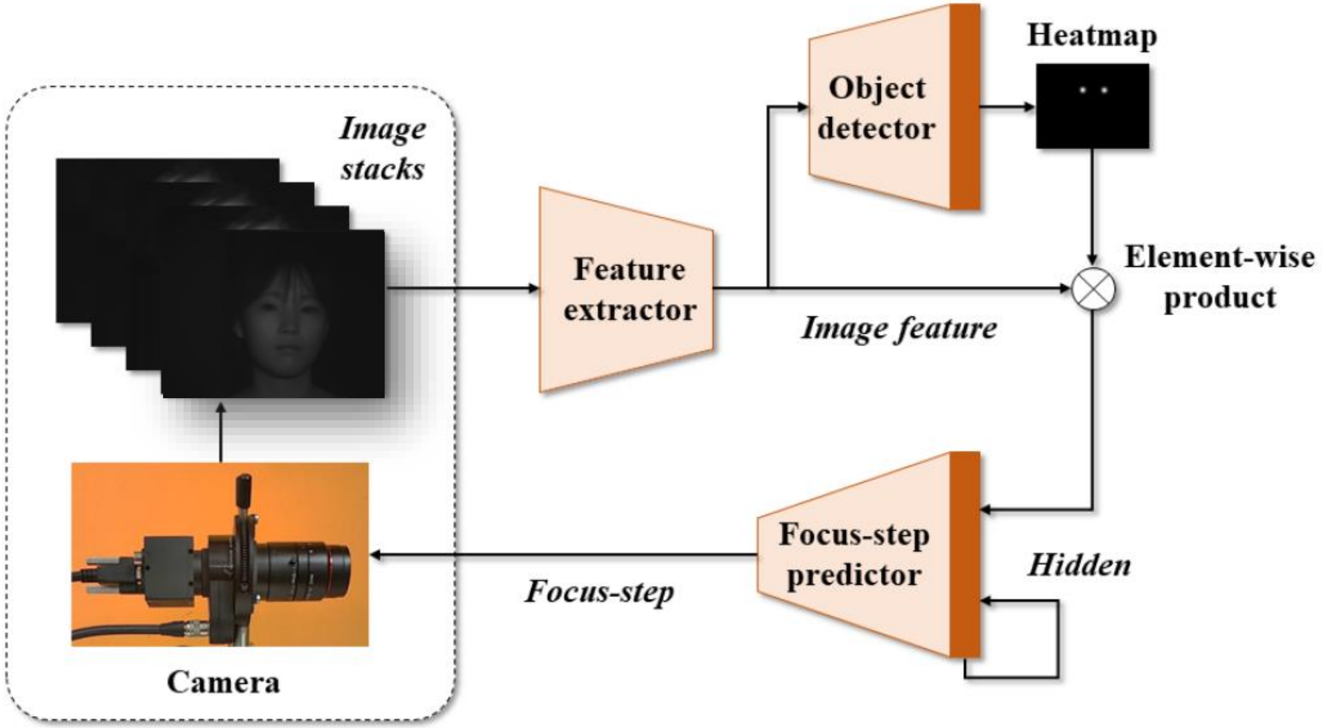
Omni all-in-focus high spatial-temporal resolution imaging

- Multi-person iris
- Iris on-the-move
- Large DoF
- Omnidirectional

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***)

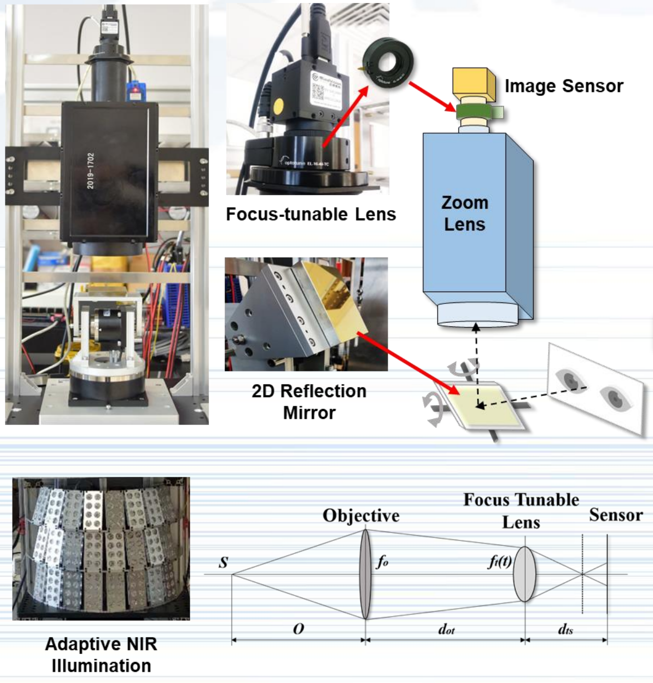
Deep Learning Assisted Iris Autofocus



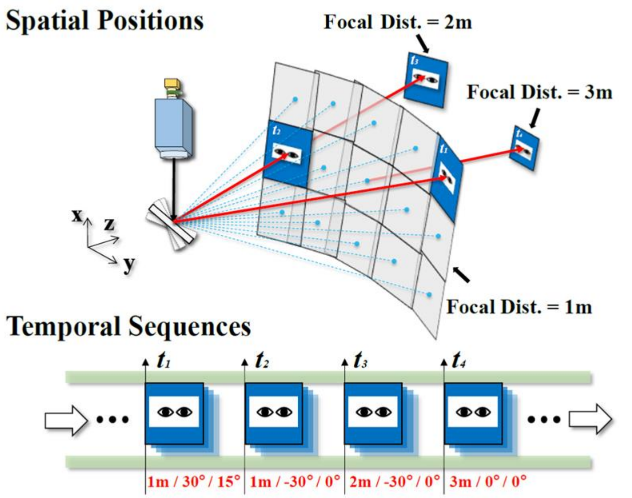


Leyuan Wang, Kunbo Zhang, Yunlong Wang, Zhenan Sun. "An End-to-End Autofocus Camera for Iris on the Move," IEEE International Joint Conference on Biometrics (***IJCB***), 2021.

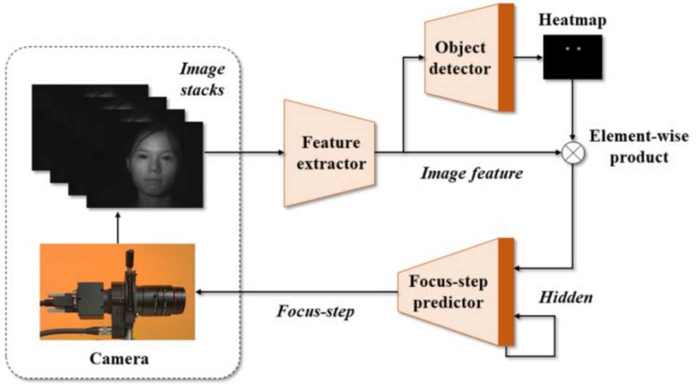
CASIA Long-range (10m) Prototype



Hardware Design

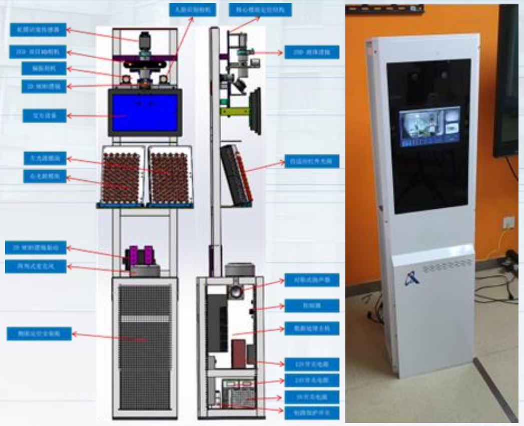


Spatiotemporal Multiplexing Imaging



End-to-end Iris Autofocus

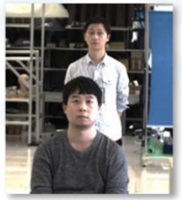
Prototype I

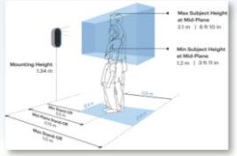


Prototype II

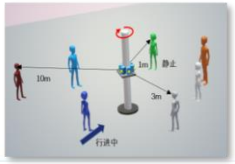
CASIA Long-range (10m) Prototype

Larger DoF

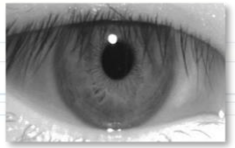




Wider FoV



Higher Resolution at a distance



Active Imaging

Multiple Persons

Small DoF	Narrow FoV	Single person
20cm	<10° (no PTZ)	

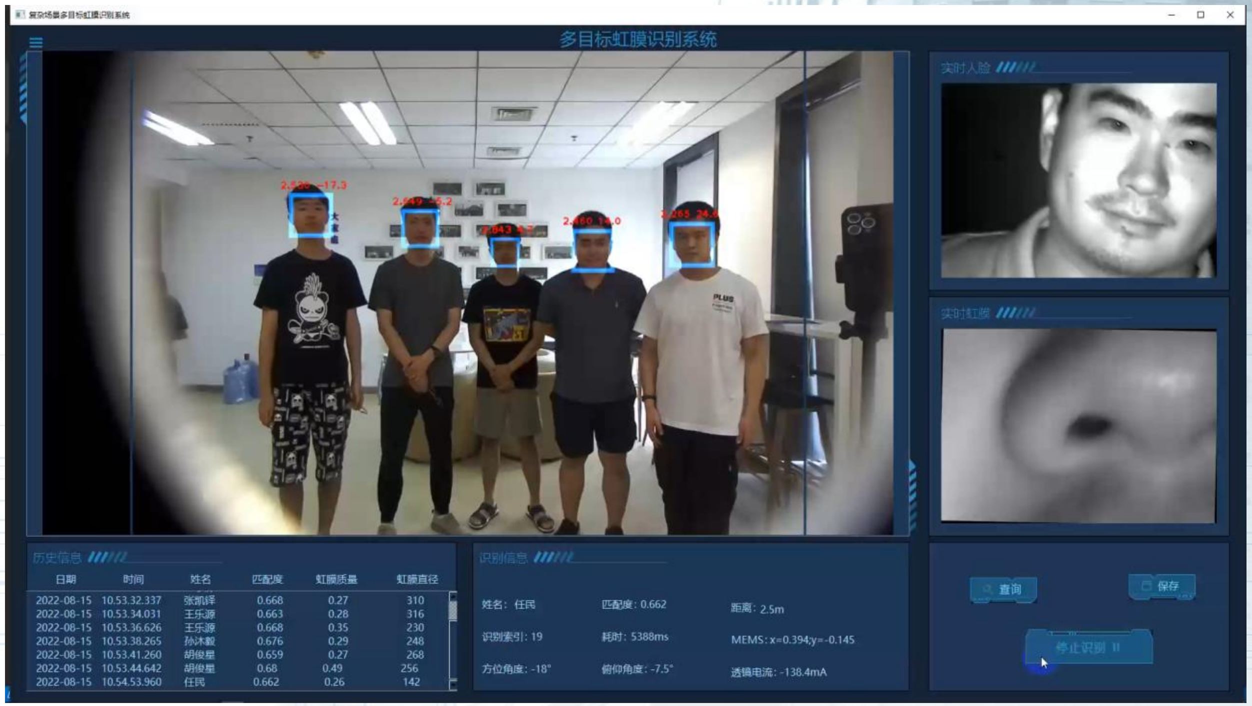
→

Large DoF	Wide FoV	Multiple
3.9 m@5m	360°	(≥3)

Model	Distance	Performance	Person	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

Prototype II



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.

lear texture iris images

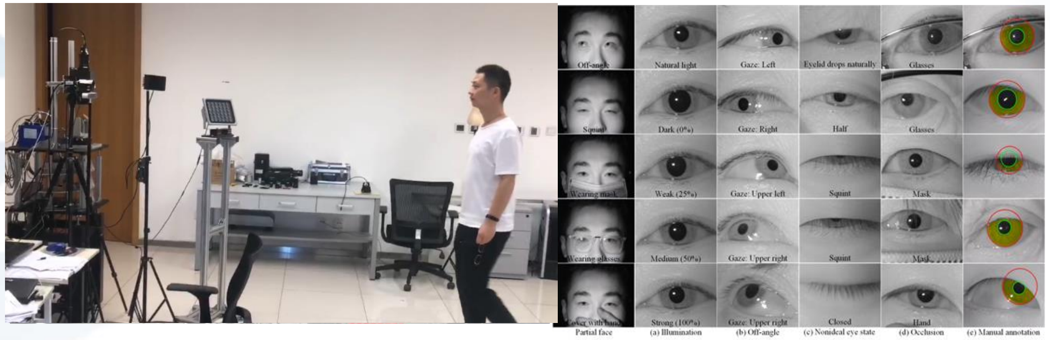
ue to illumination

ty iris/face

taset of one

is 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-Complex

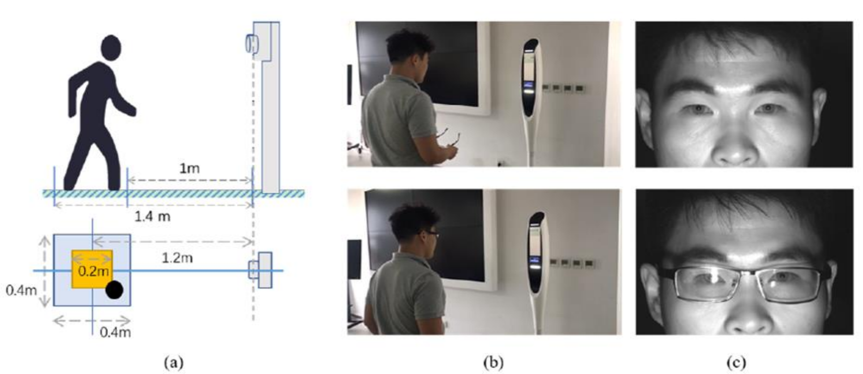
(CASIA Long-range Prototype I)

Diverse iris quality, multiple distances, cross-sensor

CASIA-Iris-Africa

(IrisKing IKUSBE30)

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



CASIA-Iris-HighThroughput

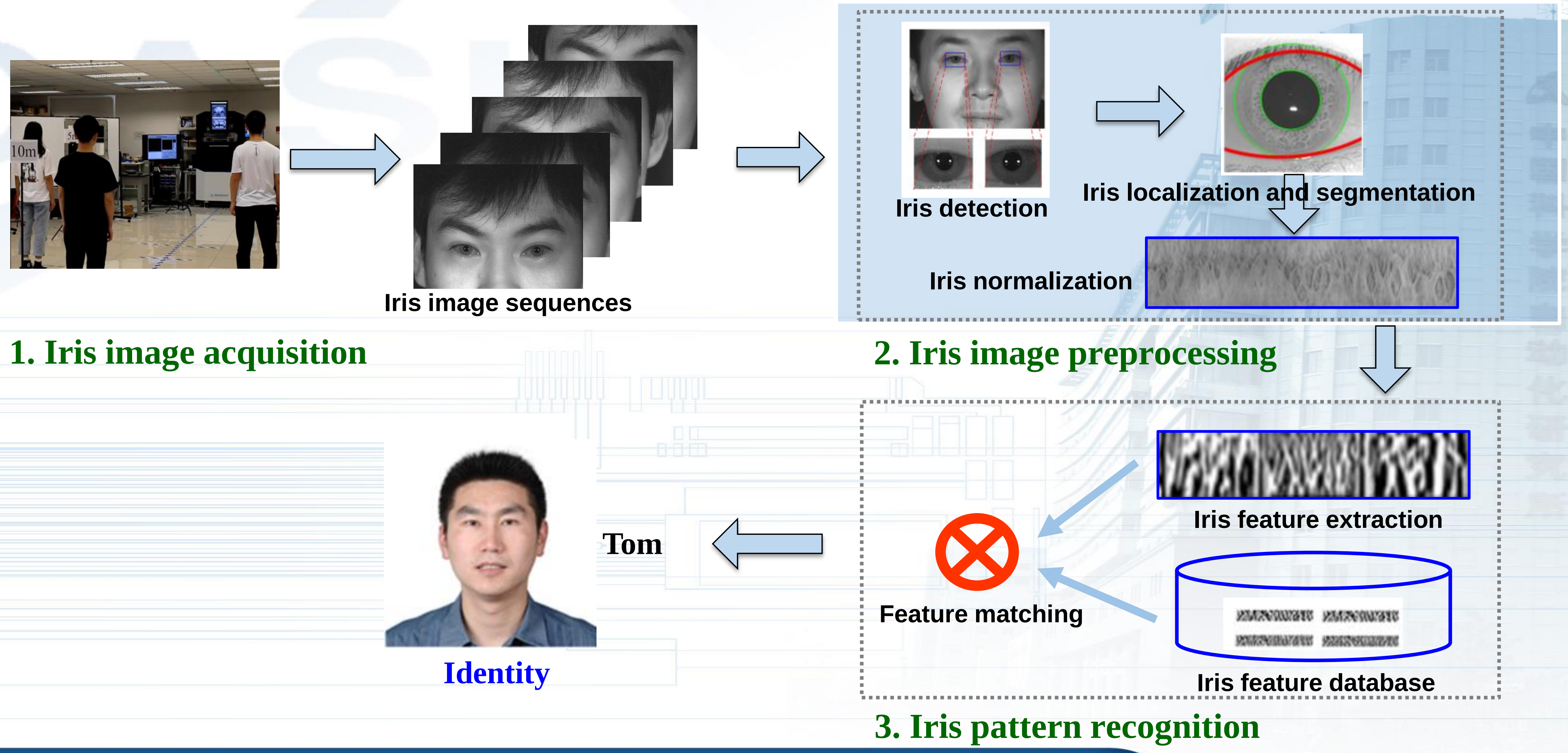
(IriStar S200P)

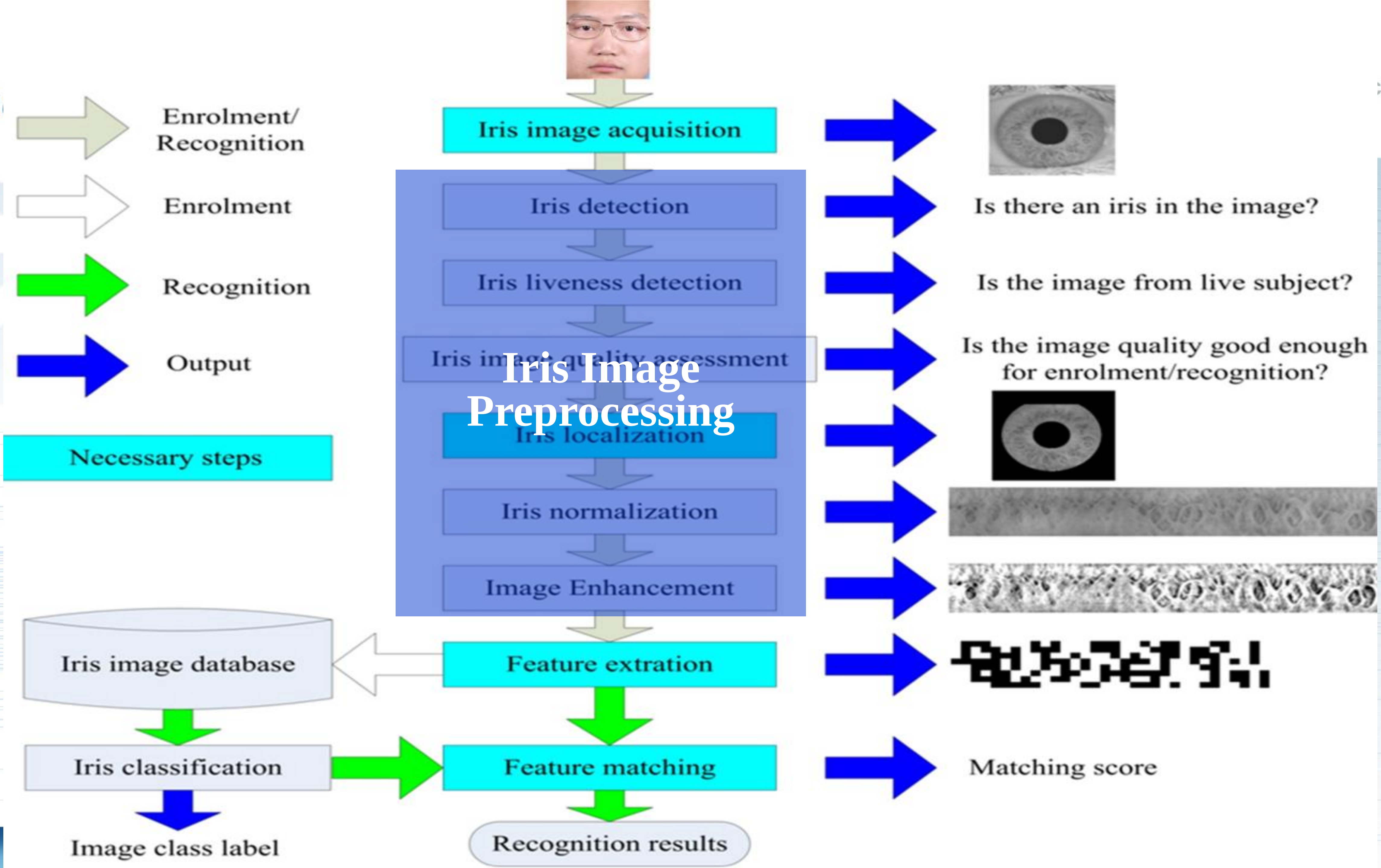
Iris image sequences, moving subjects, glasses on and off

Outline of Talk

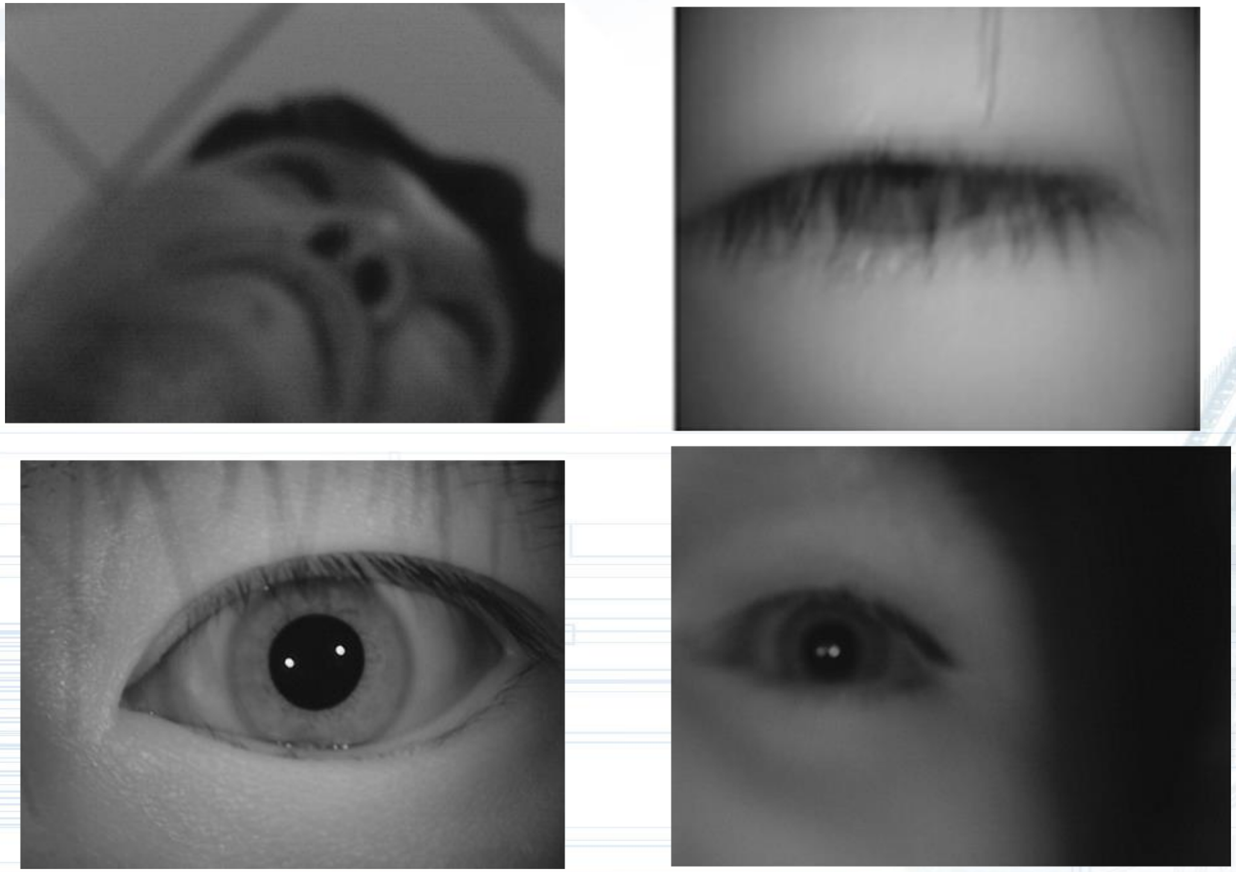
- ● Preamble
- ● Progress of Iris Recognition
  - ✓ Iris image acquisition
  - ✓ Iris image preprocessing
  - ✓ Iris pattern recognition
- ●Applications of Iris Recognition
- ●Challenges and Future Directions

Flowchart of Iris Recognition



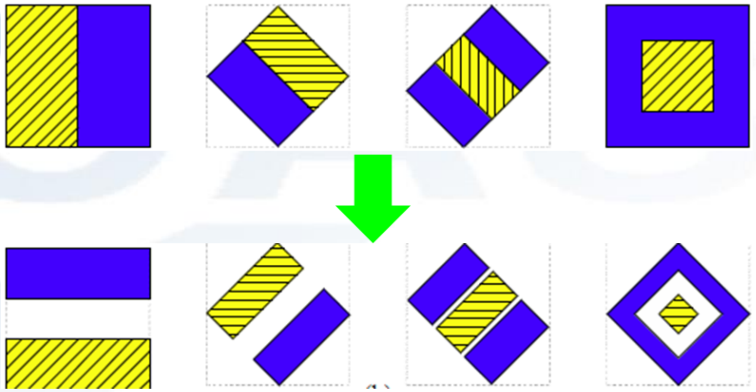

Enrolment/
Recognition
Enrolment
Recognition
Output
Necessary steps
Iris image acquisition
Iris detection
Iris liveness detection
Iris image quality assessment
Iris Image
Preprocessing
Iris localization
Iris normalization
Image Enhancement
Feature extration
Feature matching
Recognition results
Iris image database
Iris classification
Image class label
Is there an iris in the image?
Is the image from live subject?
Is the image quality good enough
for enrolment/recognition?
Matching score

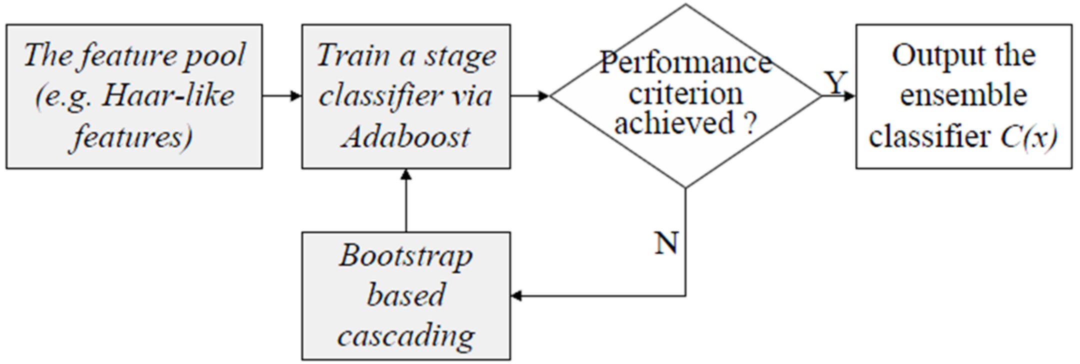
Iris Detection

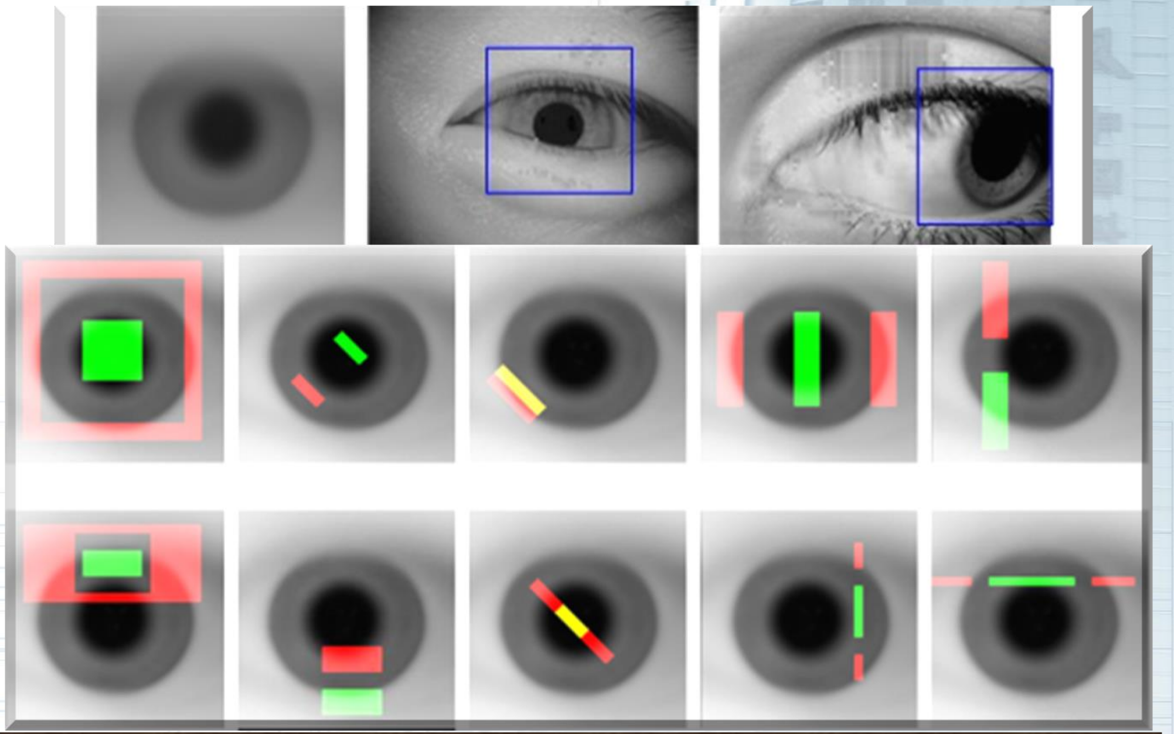


Is there an iris in the input image?

Solutions to Iris Detection



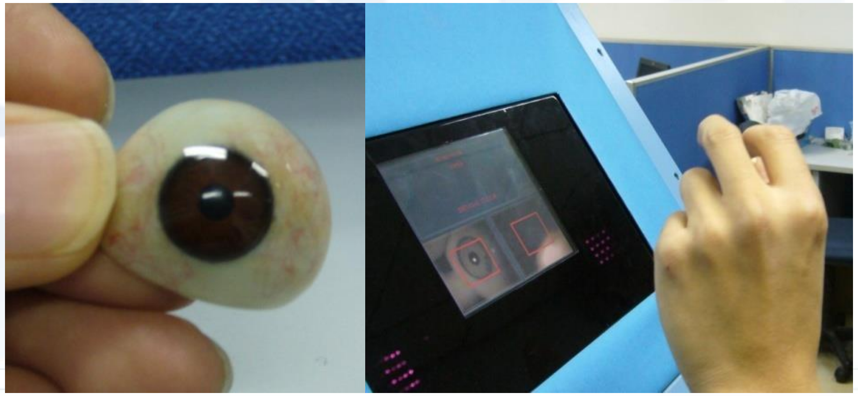




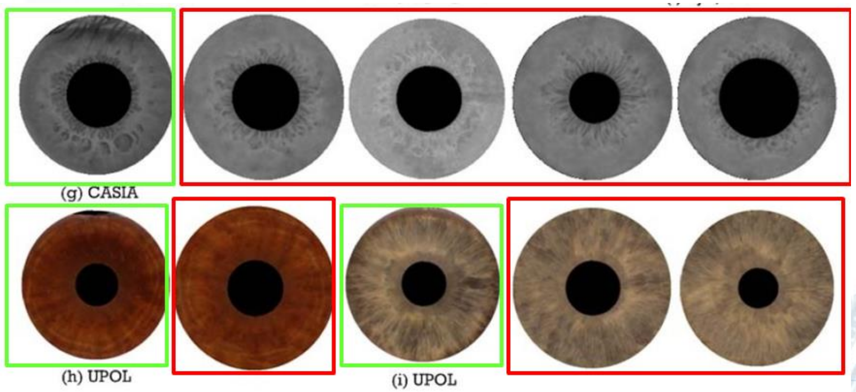
Correct detection rate is 99.2% on a database of 60,000 iris images

Extended Haar features + Boosting learning

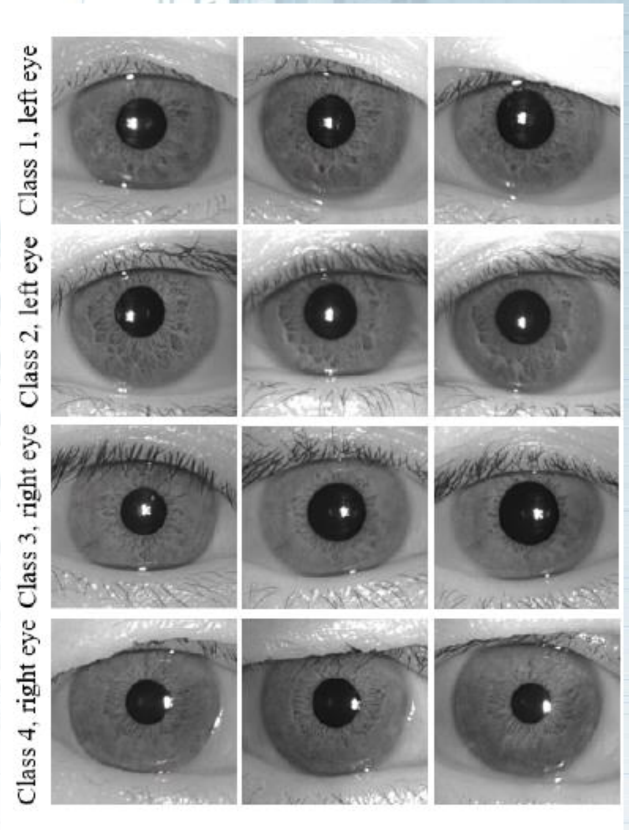
Risk of Fake Iris Attacks



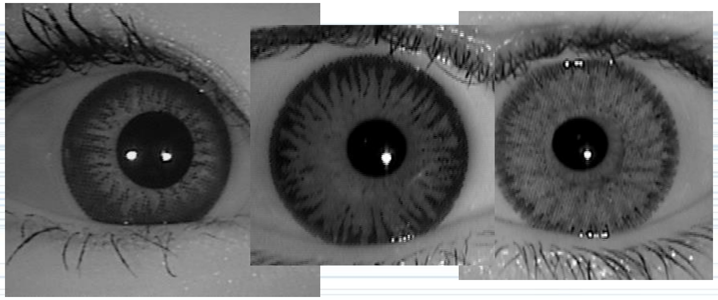
Prosthetic eye



Synthetic iris



GAN-generated iris



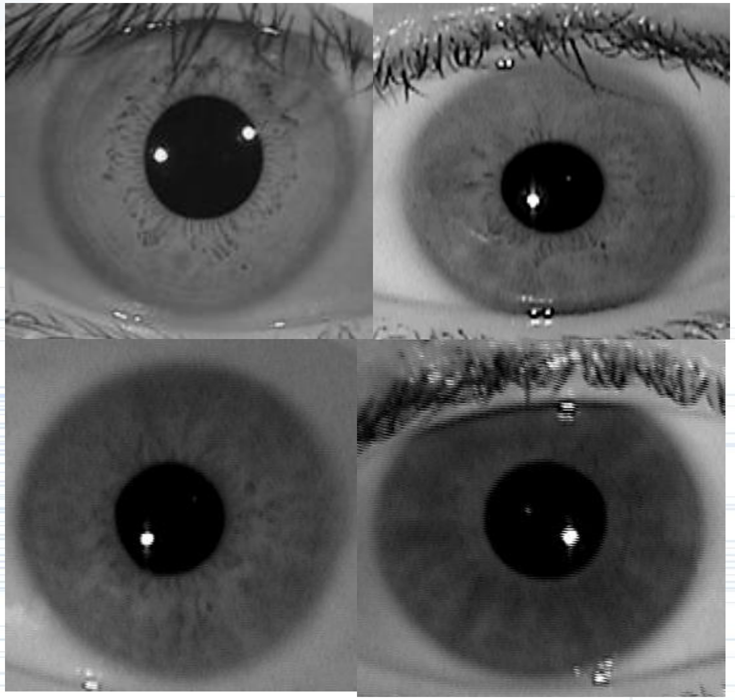
Contact lens

Screen-displayed iris

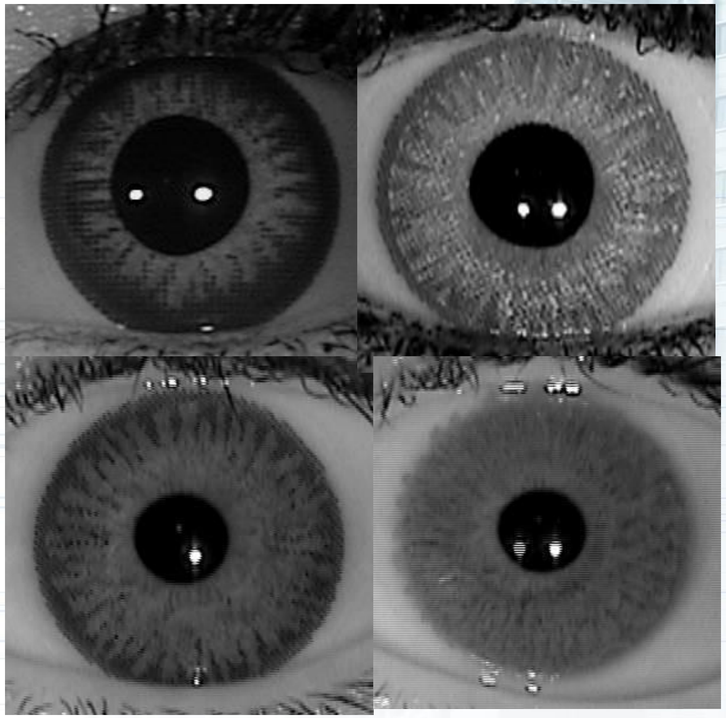
Printed iris

Iris Liveness Detection: A Texture Solution

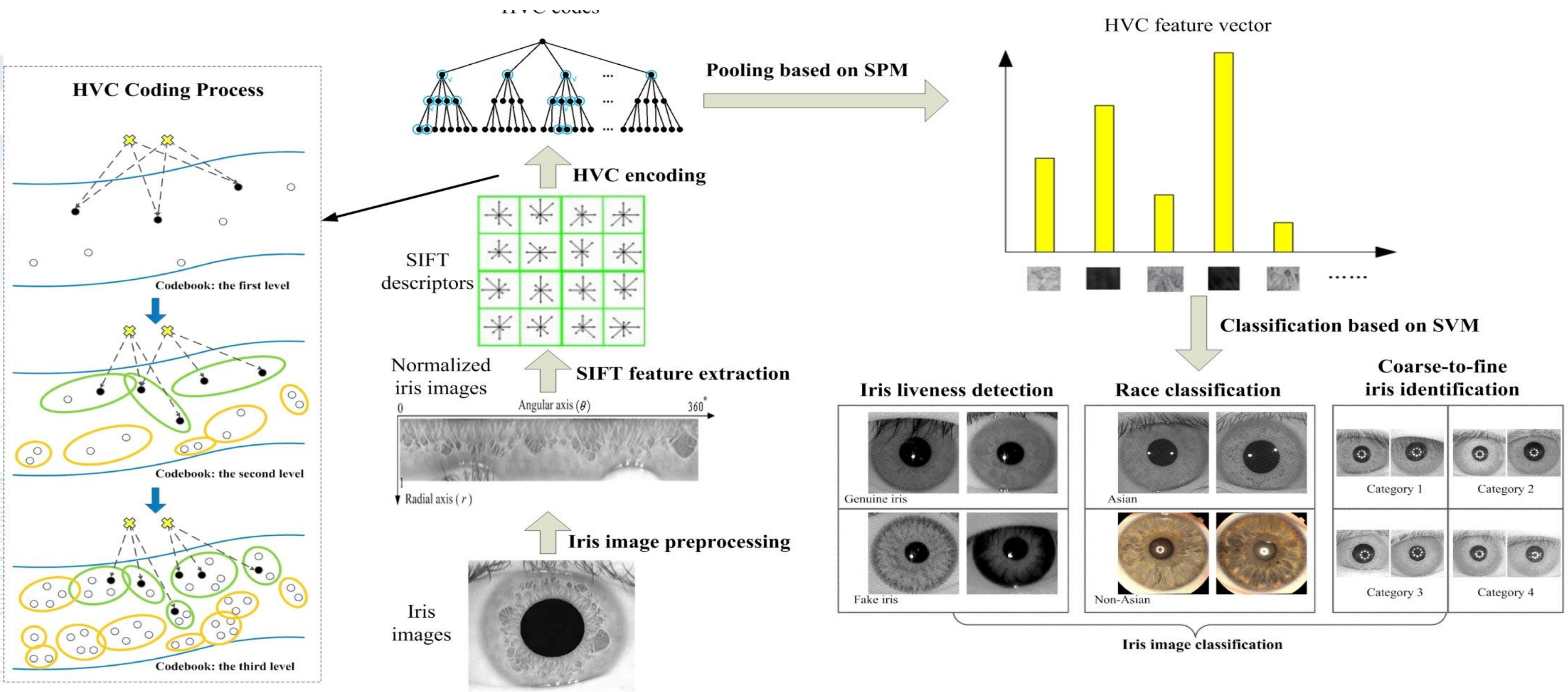
Genuine iris images:
smooth texture



Fake iris images:
coarse texture

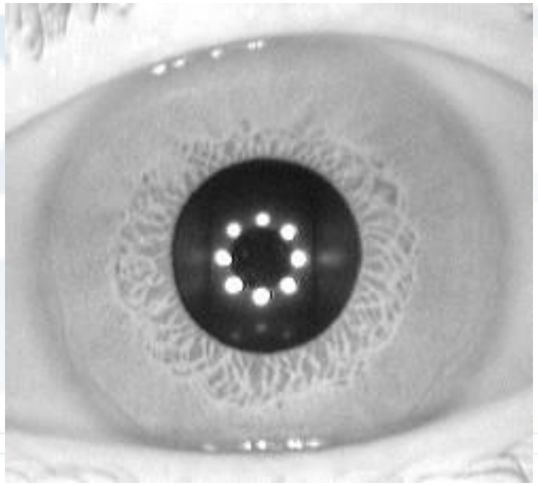


Iris Image Classification for Iris Liveness Detection

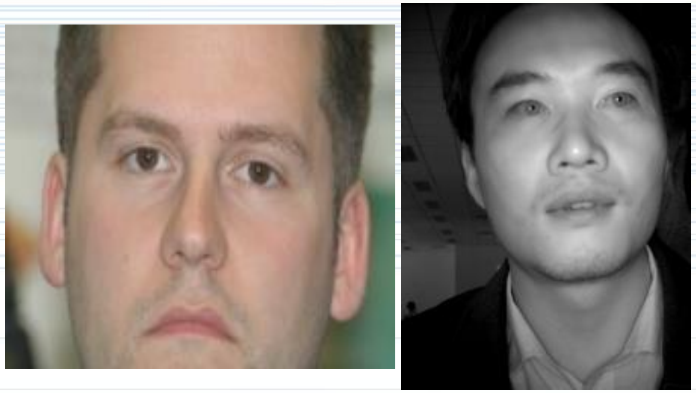


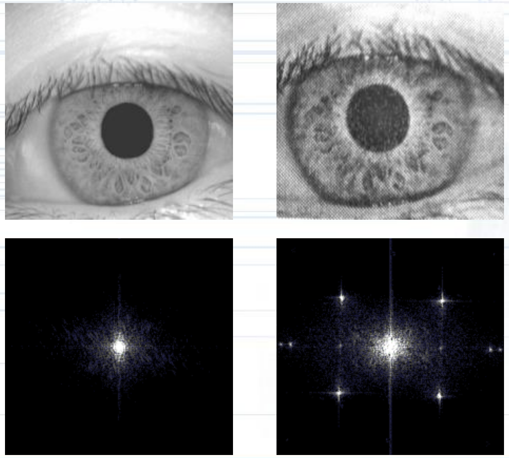
Zhenan Sun, Hui Zhang, Tieniu Tan, and Jianyu Wang, "Iris Image Classification Based on Hierarchical Visual Codebook," IEEE Transactions on Pattern Analysis and Machine Intelligence (T-PAMI), Vol. 36, No. 6, pp.1120-1133, 2014.

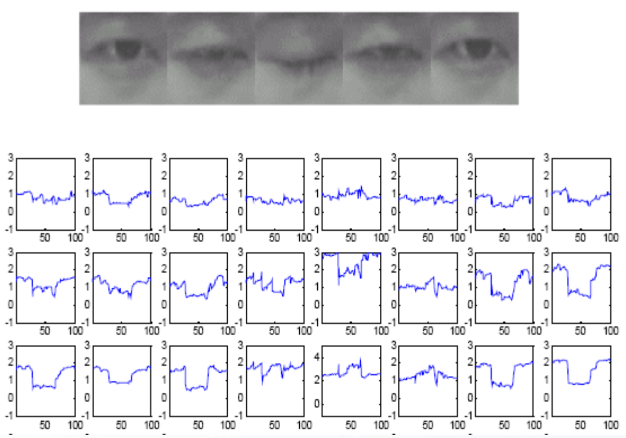
Other Possible Ways for Iris Liveness Detection



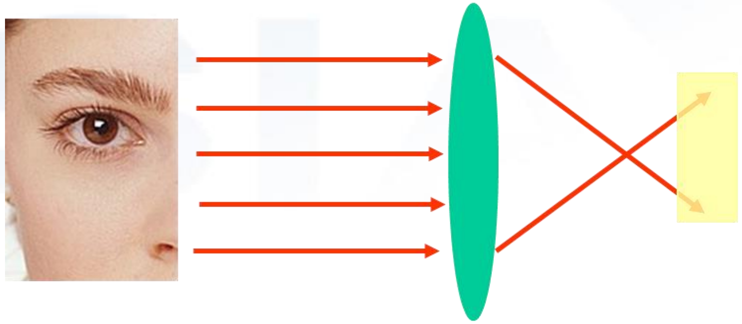
1. Spectrographic and stereoscopic properties of eyes
2. Specular reflections caused light spots
3. Eyelid movement
4. Challenge-response
5. Facial features, head movement, body sway, etc.
6. Multi-biometrics

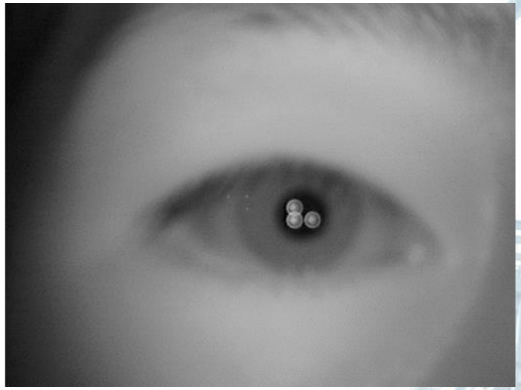


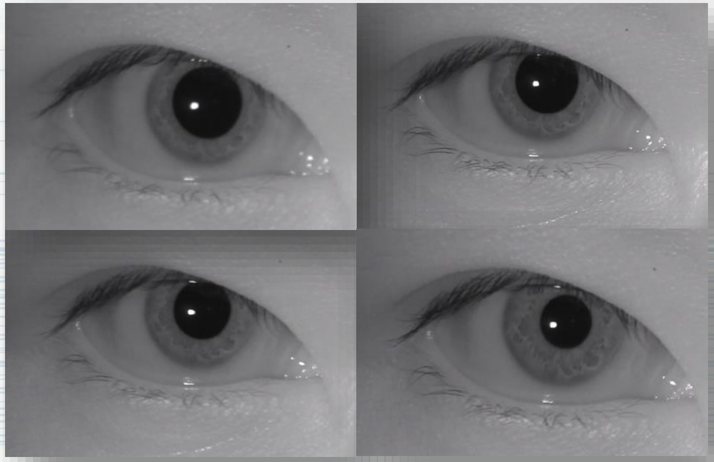




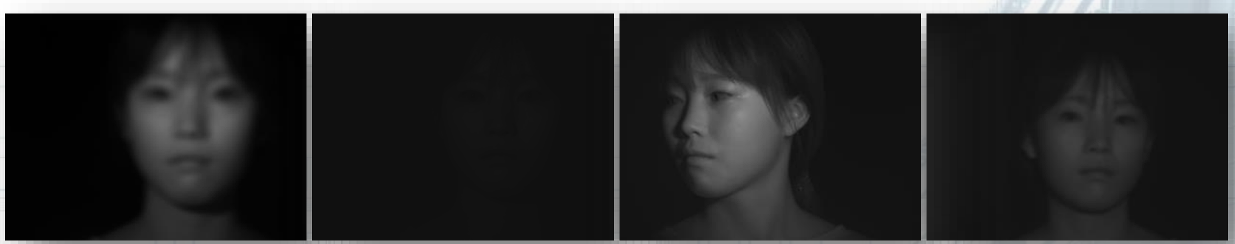
Iris Image Quality Assessment





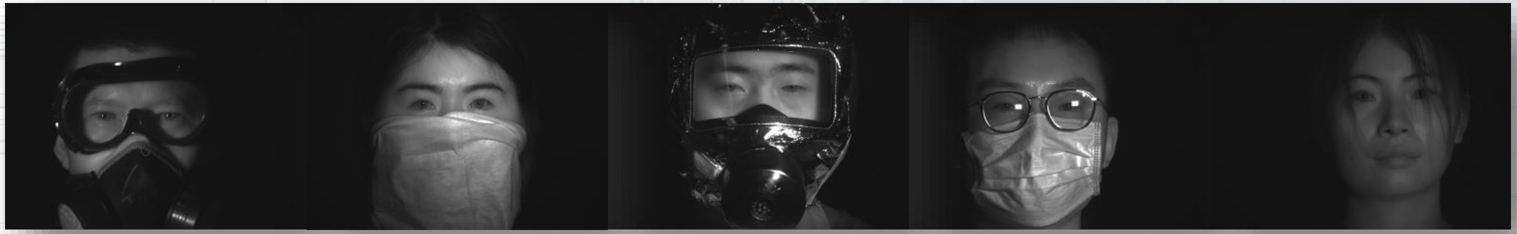


Pupil dilation and contraction



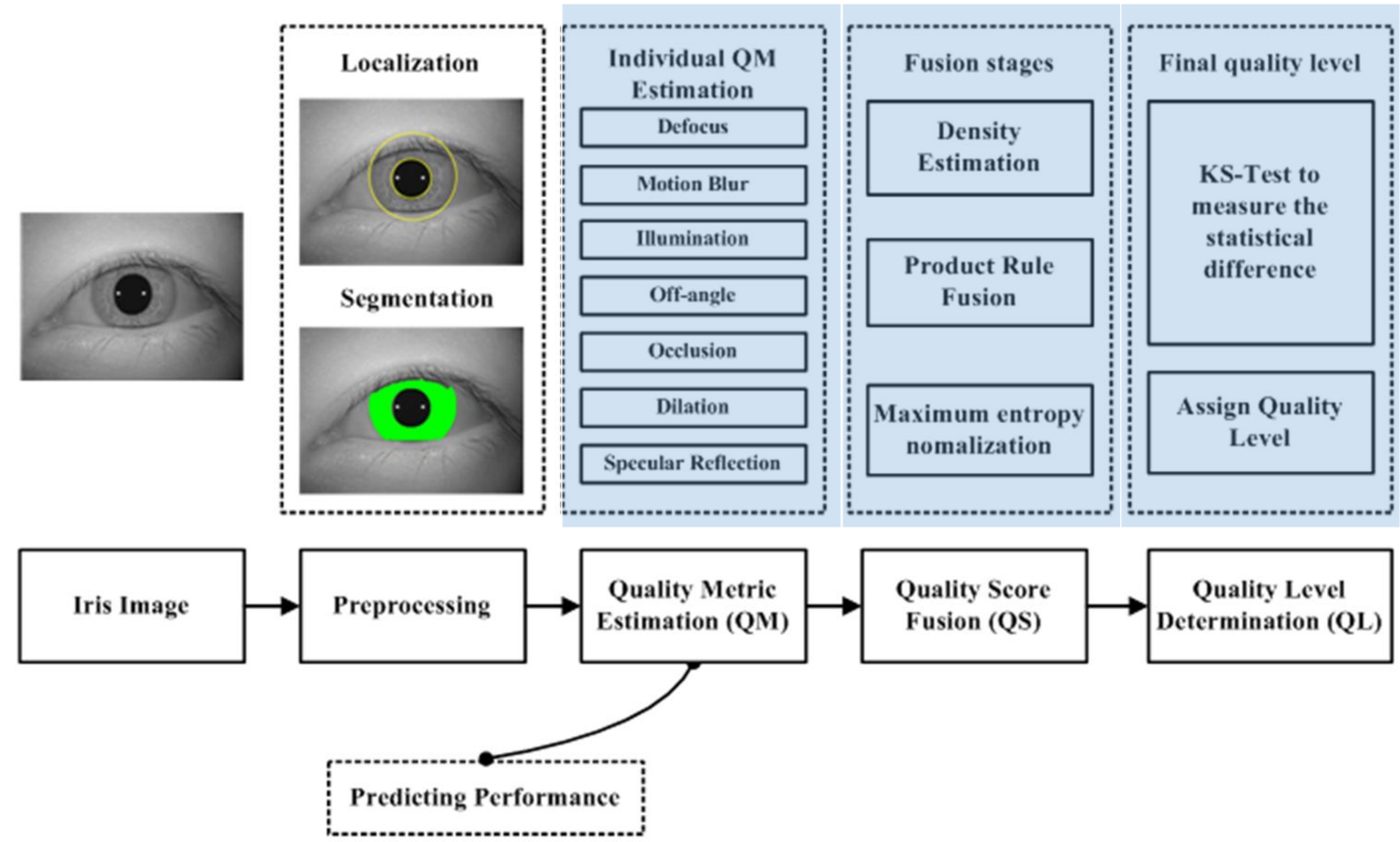
Blur, illumination, head pose, motion

Off-angle



Occlusions

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



The first Q: Quality Metric Estimation

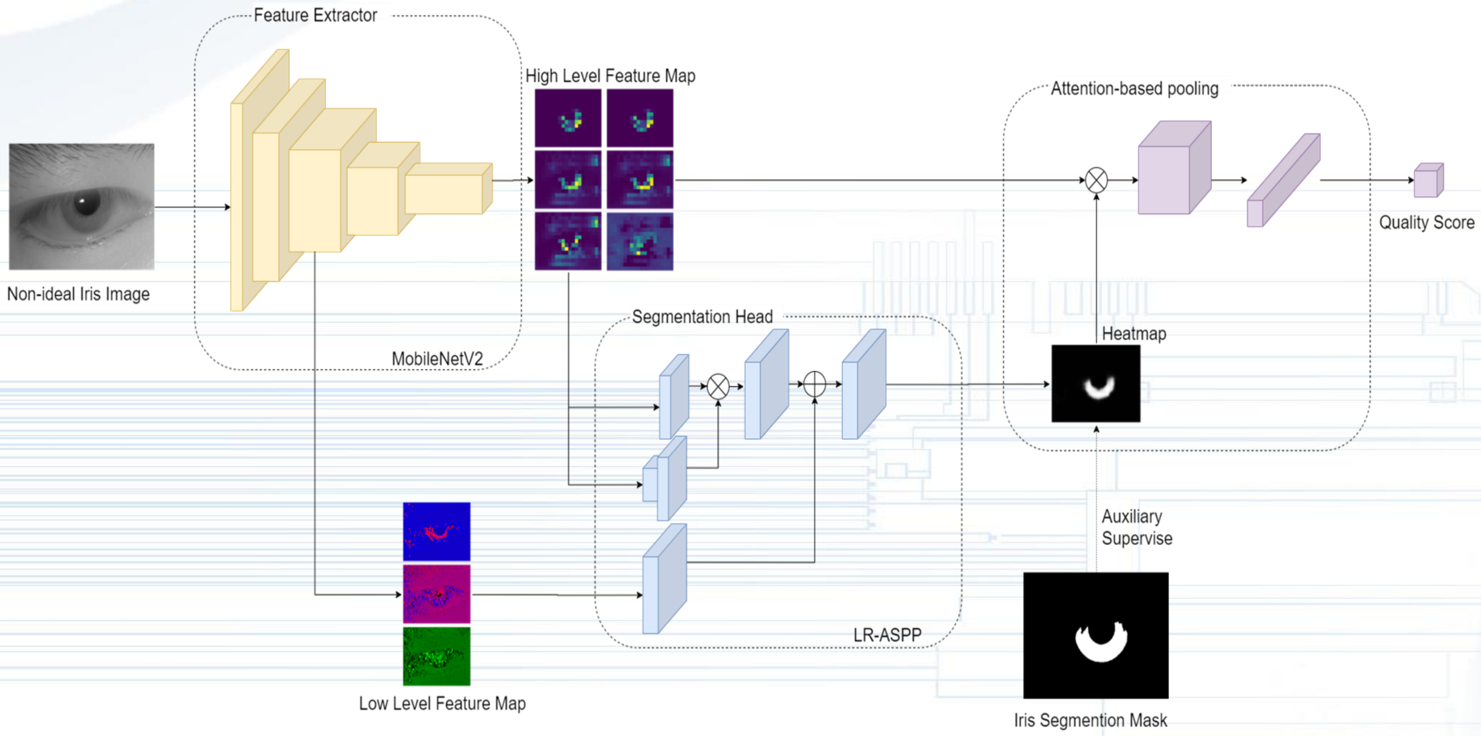
The second Q: Quality Score Fusion from Multiple Metrics

The third Q: Quality Level Determination

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.

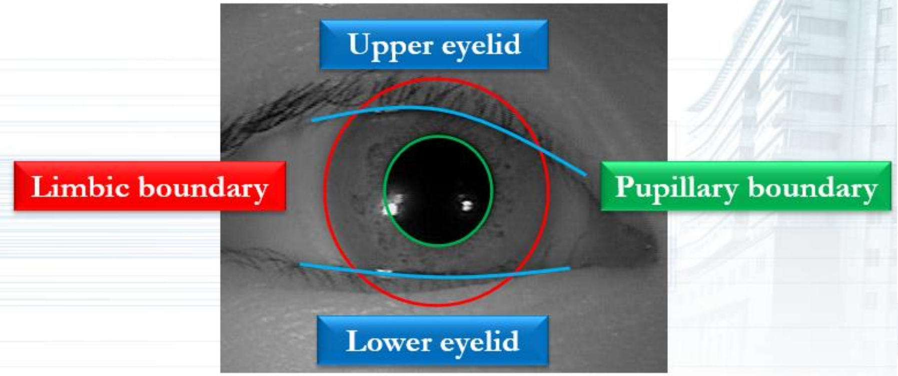


- Distance to high-quality iris images in Feature Space (DFS) is used as the ground-truth quality metric
- Prediction of iris quality score is based on deep neural networks with the attention mechanism
- More iris images are possibly selected for recognition

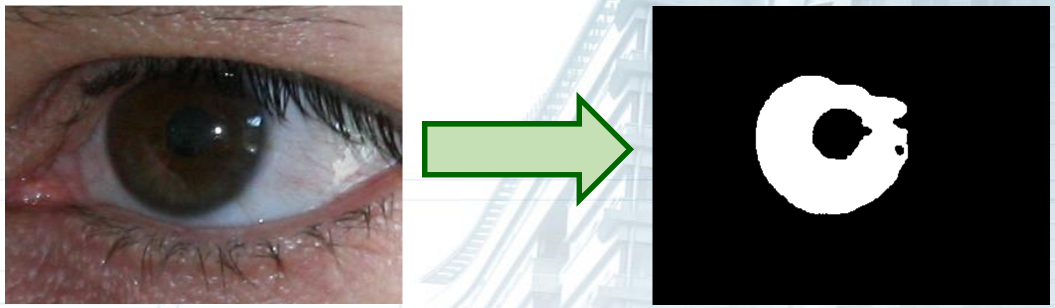
Leyuan Wang, Kunbo Zhang, Min Ren, Yunlong Wang, Zhenan Sun, "Recognition Oriented Iris Image Quality Assessment in the Feature Space," IEEE International Joint Conference on Biometrics (***IJCB***), 2020.

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.

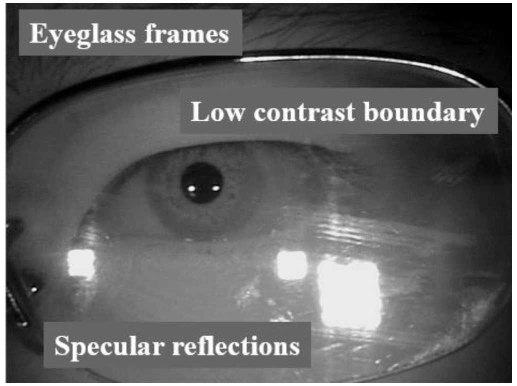


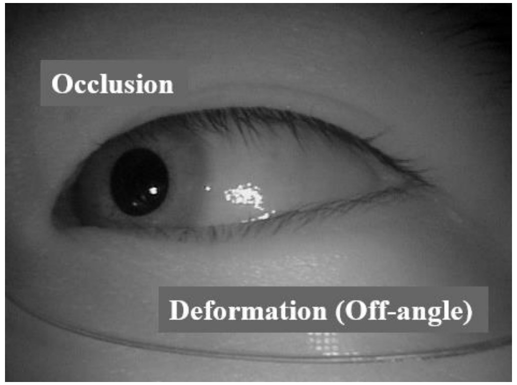
Iris Localization



Iris Segmentation

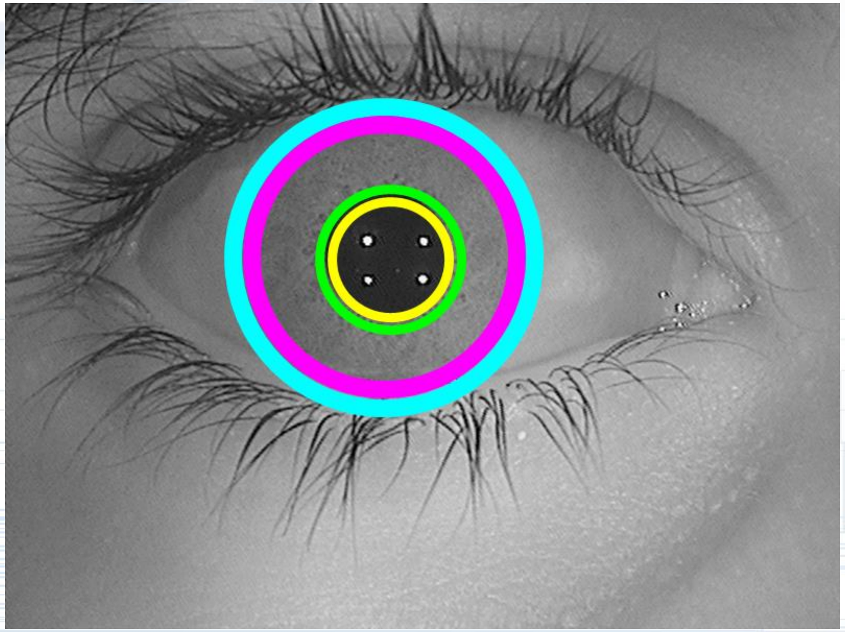
Challenges





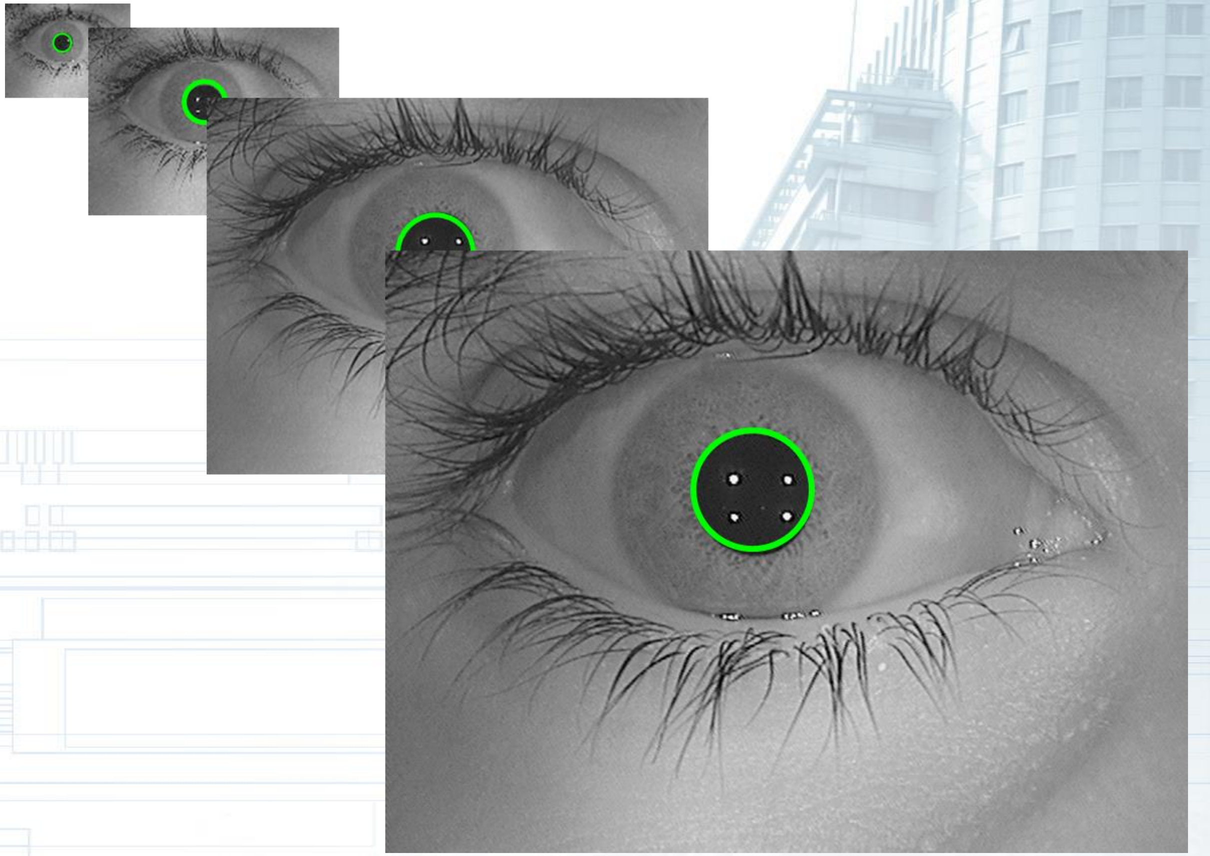
Typical Iris Localization Methods

Daugman's algorithm: coarse to fine strategy



Integral-differential operator

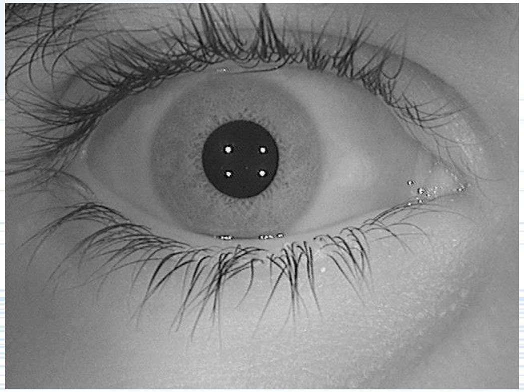
$$\max_{(r,x_0,y_0)}\left|G_\sigma(r)*\frac{\partial}{\partial r}\oint_{r,x_0,y_0}\frac{I(x,y)}{2\pi r}ds\right|$$



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

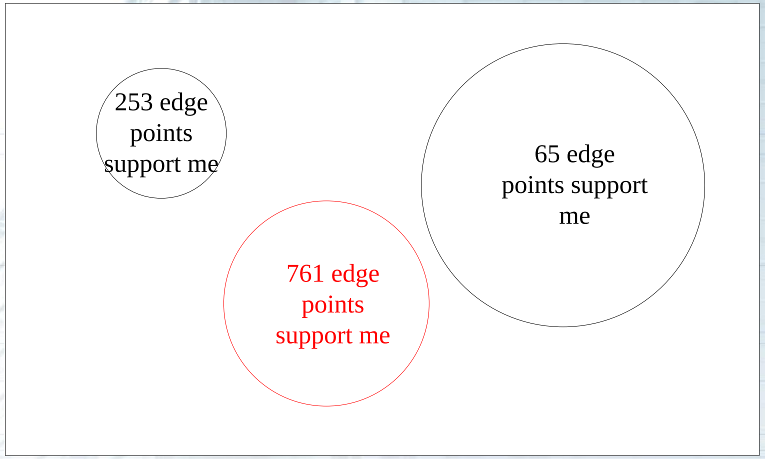
Typical Iris Localization Methods

Wildes' algorithm: Hough transform



Edge detection

Hough transform



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

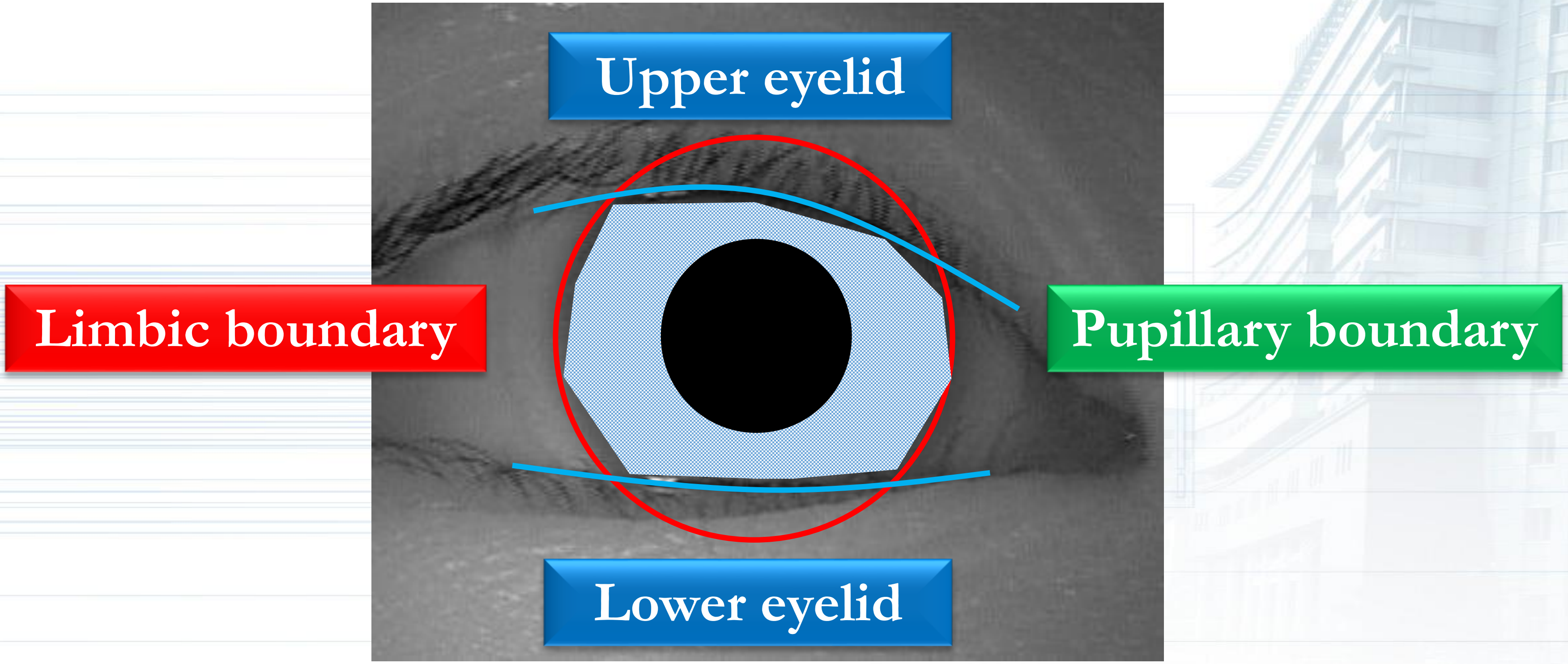
Iris Localization and Segmentation Methods

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

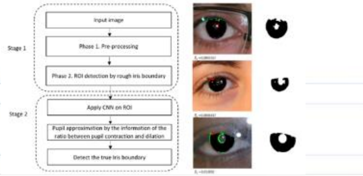
- Integrodifferential operator (Daugman, TCSVT'04)
- Hough transform (Wildes, Proc. of IEEE'97)
- Active contours (Shah and Ross, TIFS'09)
- Pulling and pushing (He, Tan et al., TPAMI'09)
- Polar Spline RANSAC (Ruggero et al., CVIU'19)



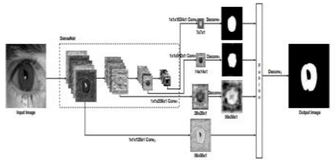
Iris Segmentation Based on Deep Learning

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

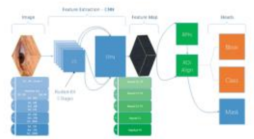
Two-stage CNN
Arsalan et al. *Symmetry 2017*



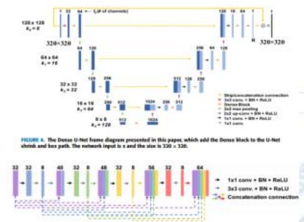
SegDenseNet
Lakra et al. *ICPR 2018*



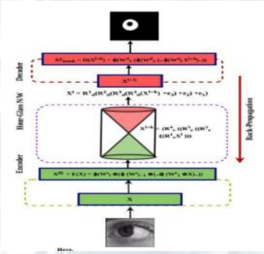
Modified Mask R-CNN
Ahmad et al. *ACCV 2018*



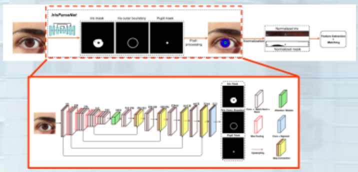
Dense U-Net
Wu et al. *IEEE Access 2019*



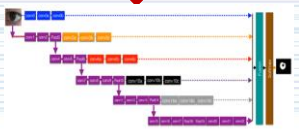
Stacked hourglass bottleneck
Jha et al. *IET Biometrics 2019*



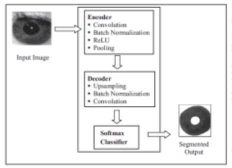
Joint Iris Segmentation and Localization
Wang et al. *TIFS 2020*



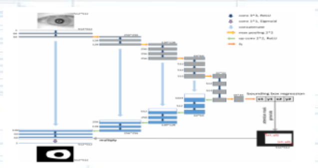
2016 **2017** **2018** **2019** **2020**



Multi-scale FCN(MFCNs)
Tan et al. *ICB 2016*

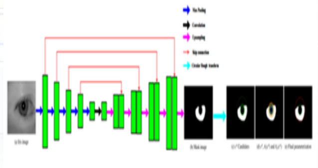


Encoder-decoder
Sinha et al. *I2CT 2017*

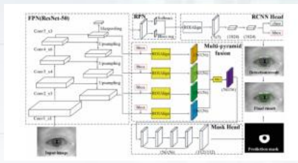


Attention U-Net
Lian et al. *J. Vis. Commun. Image R. 2018*

RefineNet and Hough transform
Hofbauer et al. *PRL 2019*

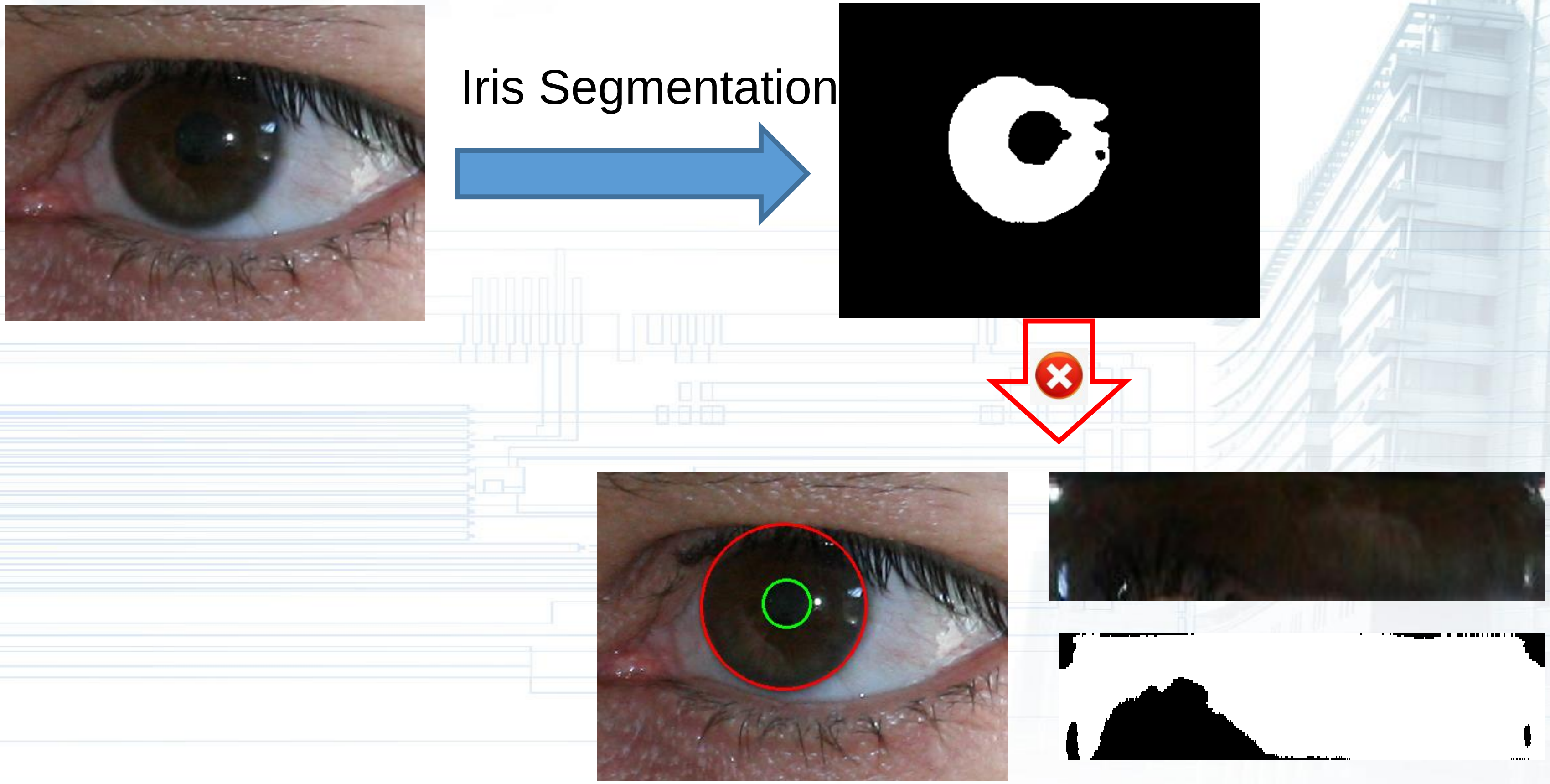


Multi-pyramid Mask R-CNN
Liang et al. *CCBR 2019*



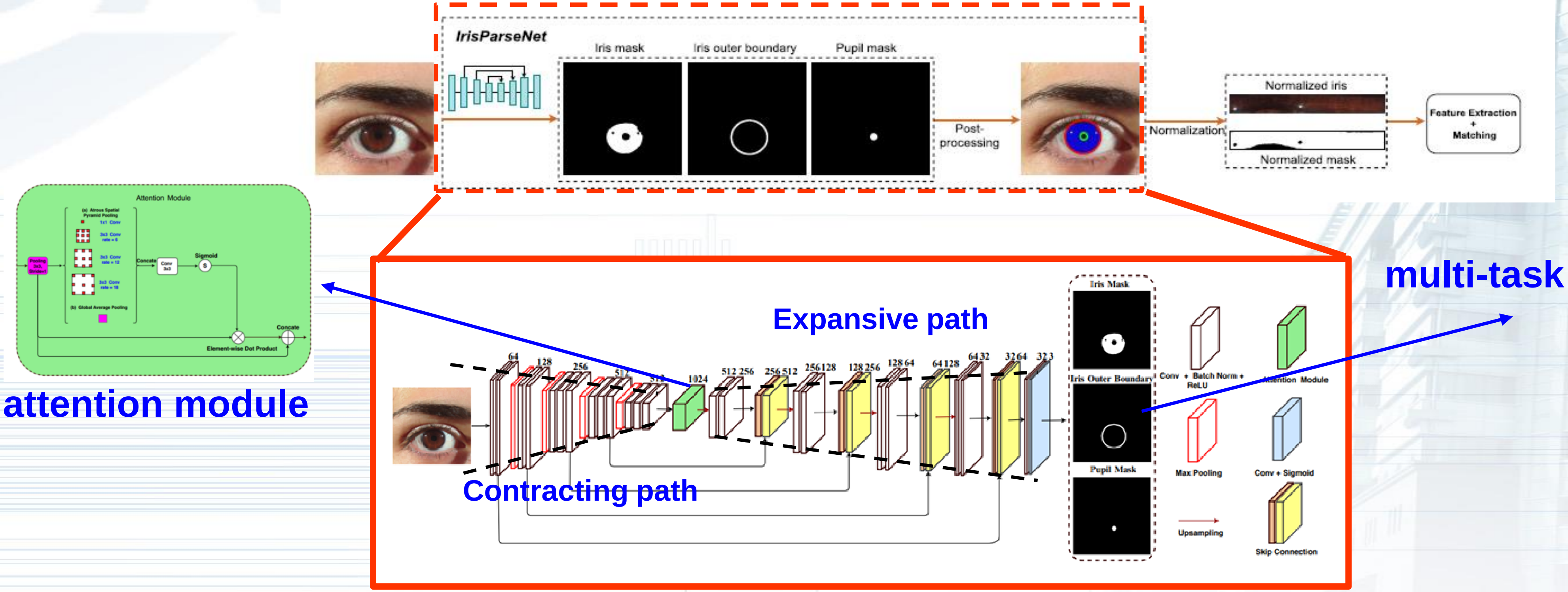
Problems of the Existing Methods

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



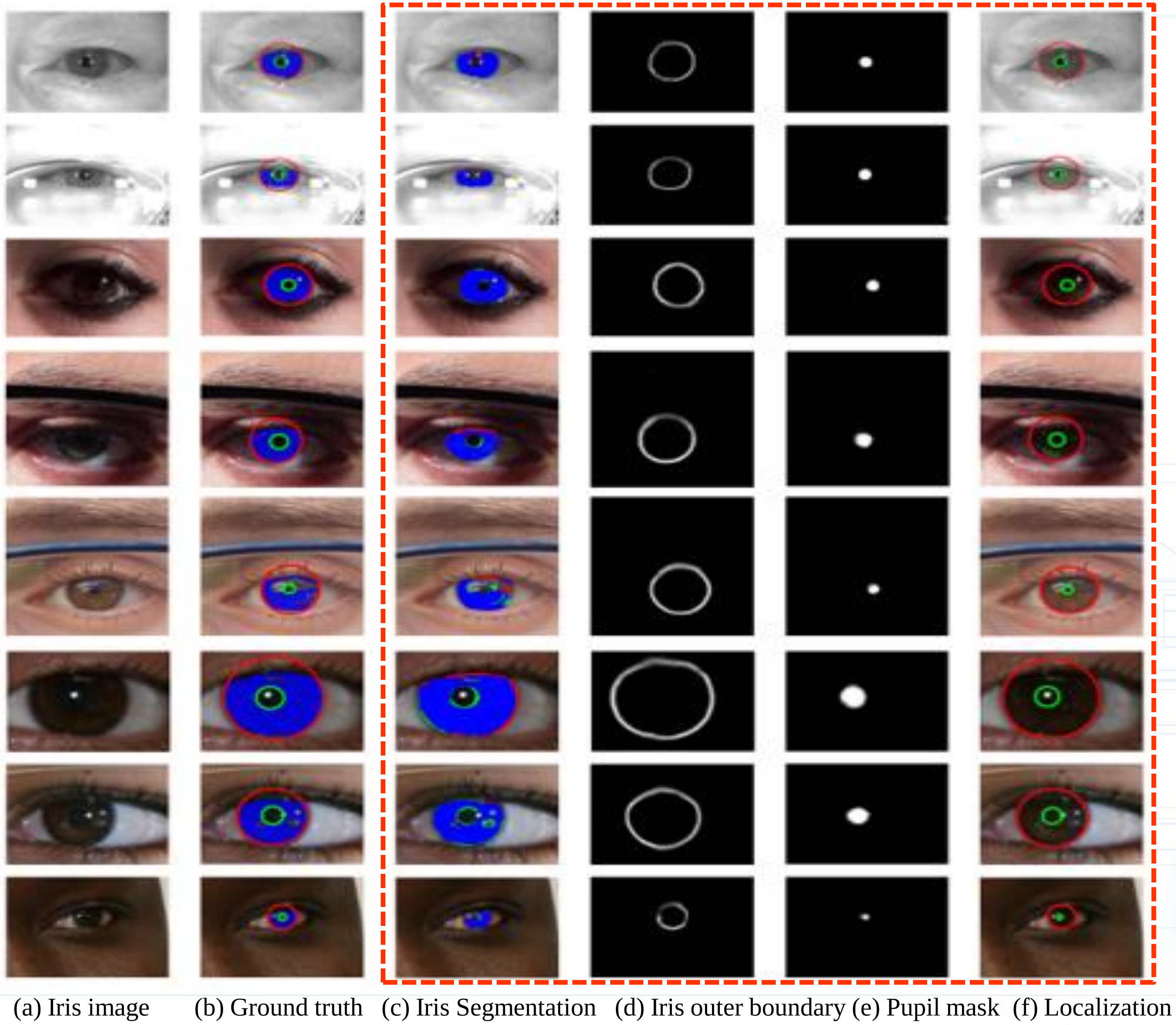
Our Solution: Simultaneous Iris Segmentation and Localization

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.



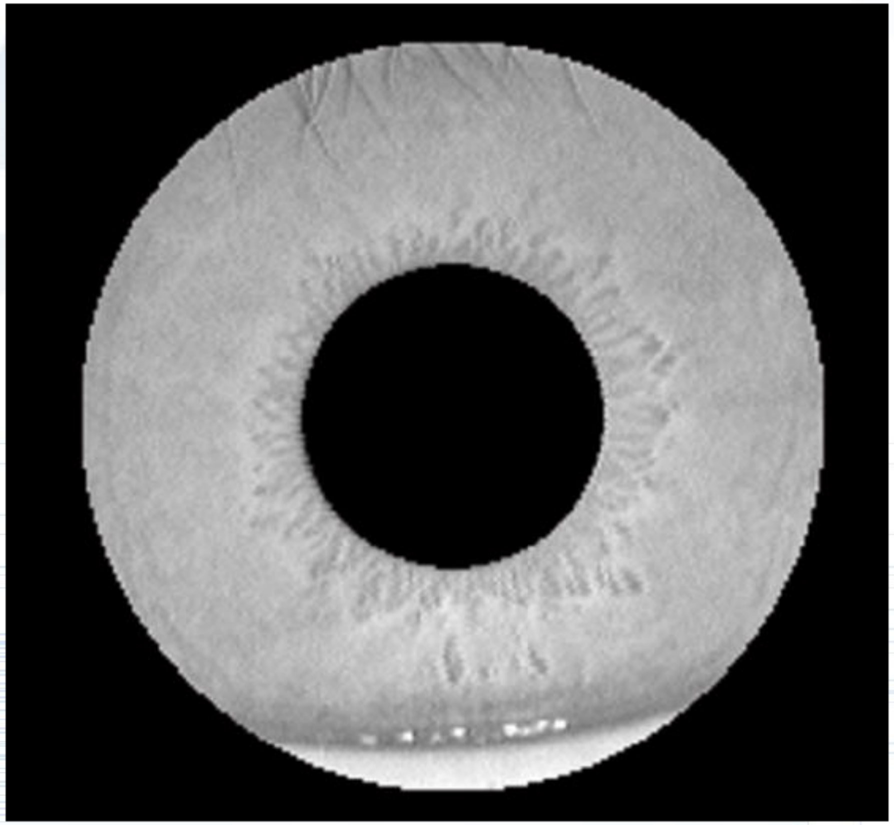
Caiyong Wang, Jawad Muhammad, Yunlong Wang, Zhaofeng He and Zhenan Sun, "Towards Complete and Accurate Iris Segmentation Using Deep Multi-task Attention Network for Non-Cooperative Iris Recognition," IEEE Transactions on Information Forensics and Security (***TIFS***), 2020, vol. 15, pp. 2944-2959, 2020.

Experimental Results of Joint Iris Segmentation and Localization

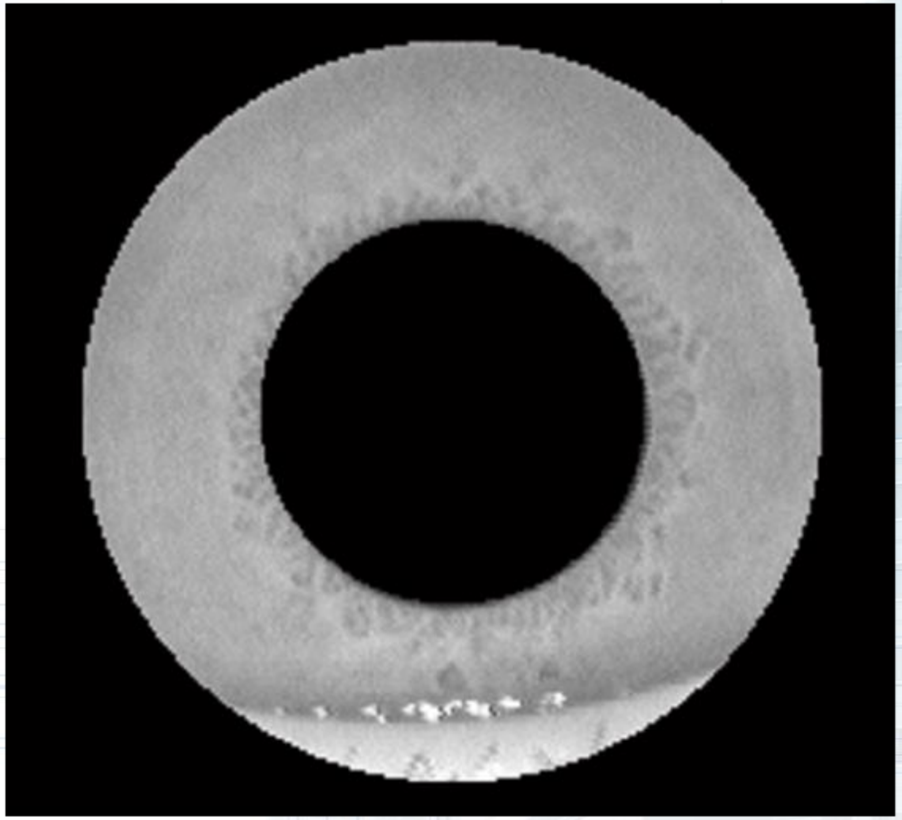


Method	Database	E1 (%)	E2 (%)	F1 (%)
T. Tan *et al.* [90]	UBIRIS.v2 (NICE.I)	1.31	N/A	N/A
RTV-L^1 [92]	CASIA.v4-distance	0.68	0.44	87.55
	UBIRIS.v2 (NICE.I)	1.21	0.83	85.97
	MICHE-I	2.42	1.21	79.24
Haindl and Krupička [93]	UBIRIS.v2 (NICE.I)	3.24	1.62	77.03
	MICHE-I	3.86	1.93	70.17
MFCNs [101]	CASIA.v4-distance	0.59	0.24	93.09
	UBIRIS.v2 (NICE.I)	0.90	0.49	91.04
	MICHE-I	0.74	0.37	92.01
CNNHT [2] (RefineNet)	CASIA.v4-distance	0.56	0.28	92.27
	UBIRIS.v2 (NICE.I)	0.97	0.48	90.34
	MICHE-I	0.80	0.40	91.41
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**

Nonlinear Iris Deformation

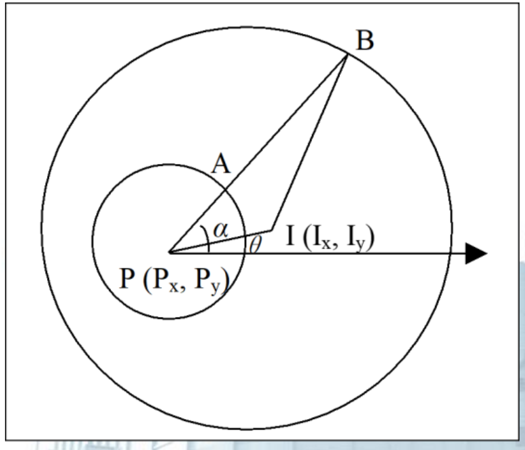


Normal illumination

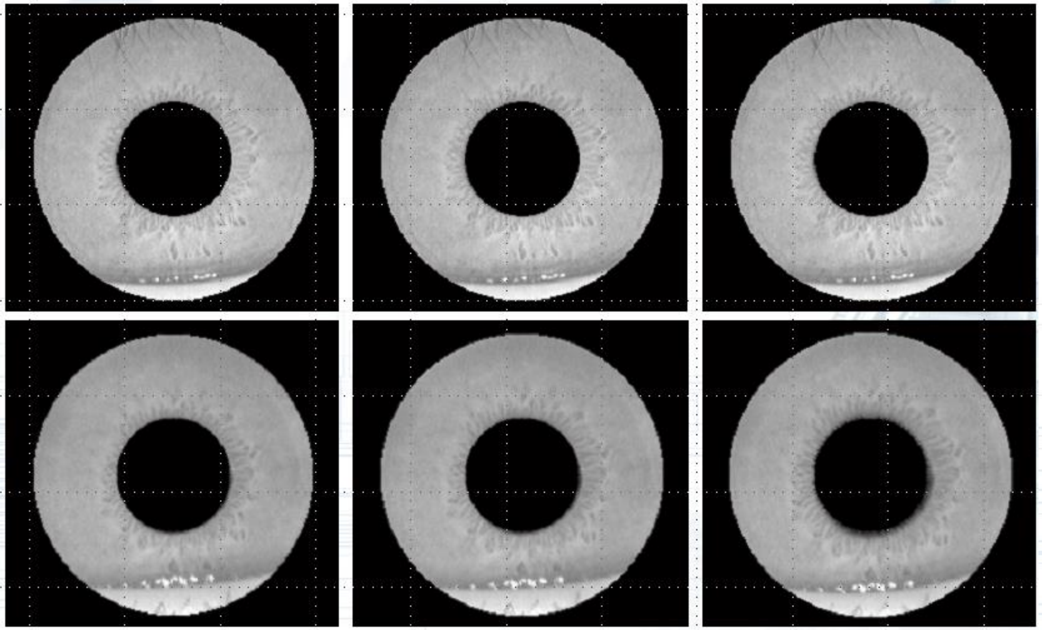


Weak illumination

Iris Normalization



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



Linear **Piecewise-linear** **Nonlinear**

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

Linear mapping model:

$$f(x) = \frac{R}{r}x$$

Piecewise-linear mapping model:

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

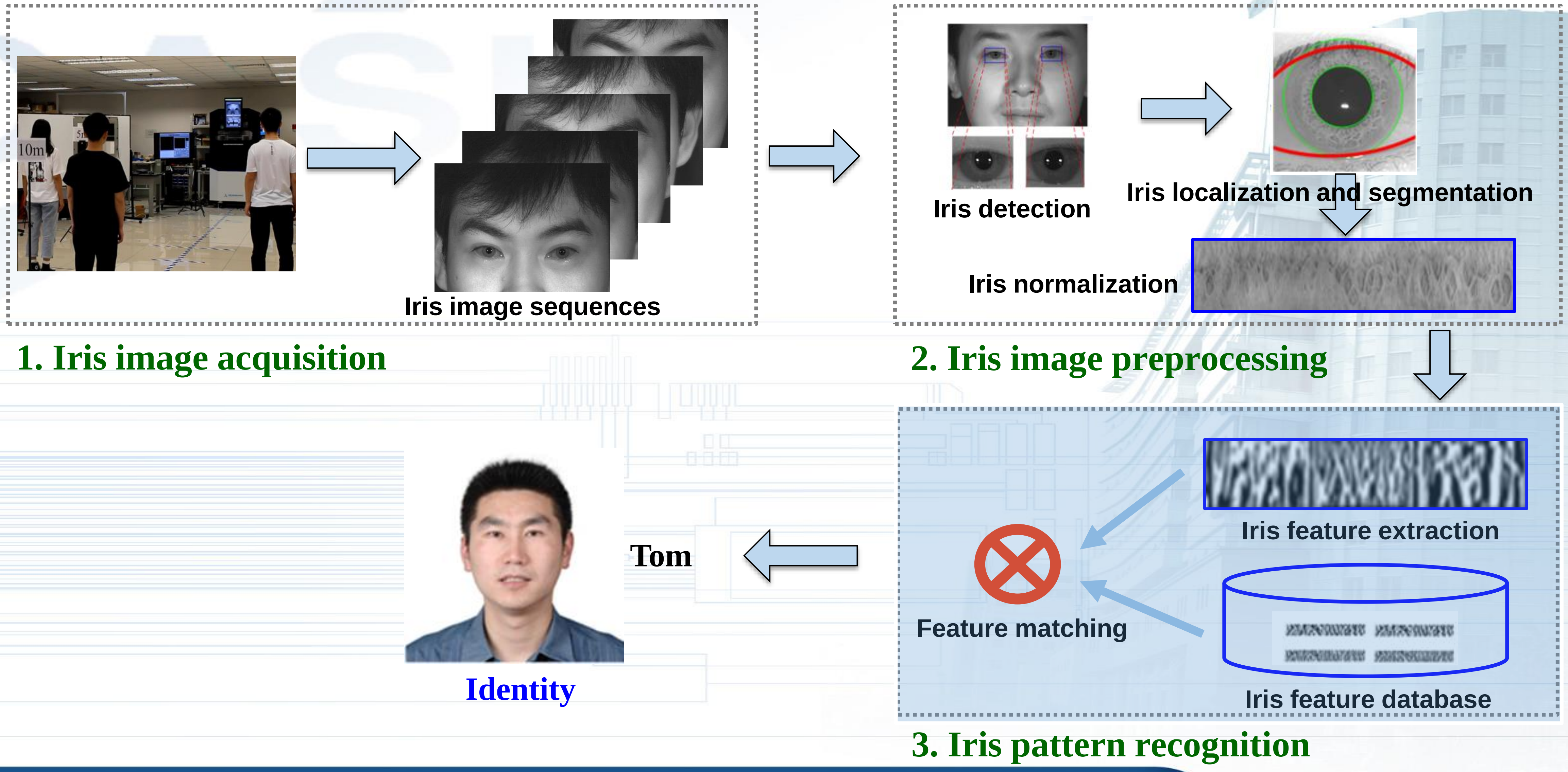
Nonlinear mapping:

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

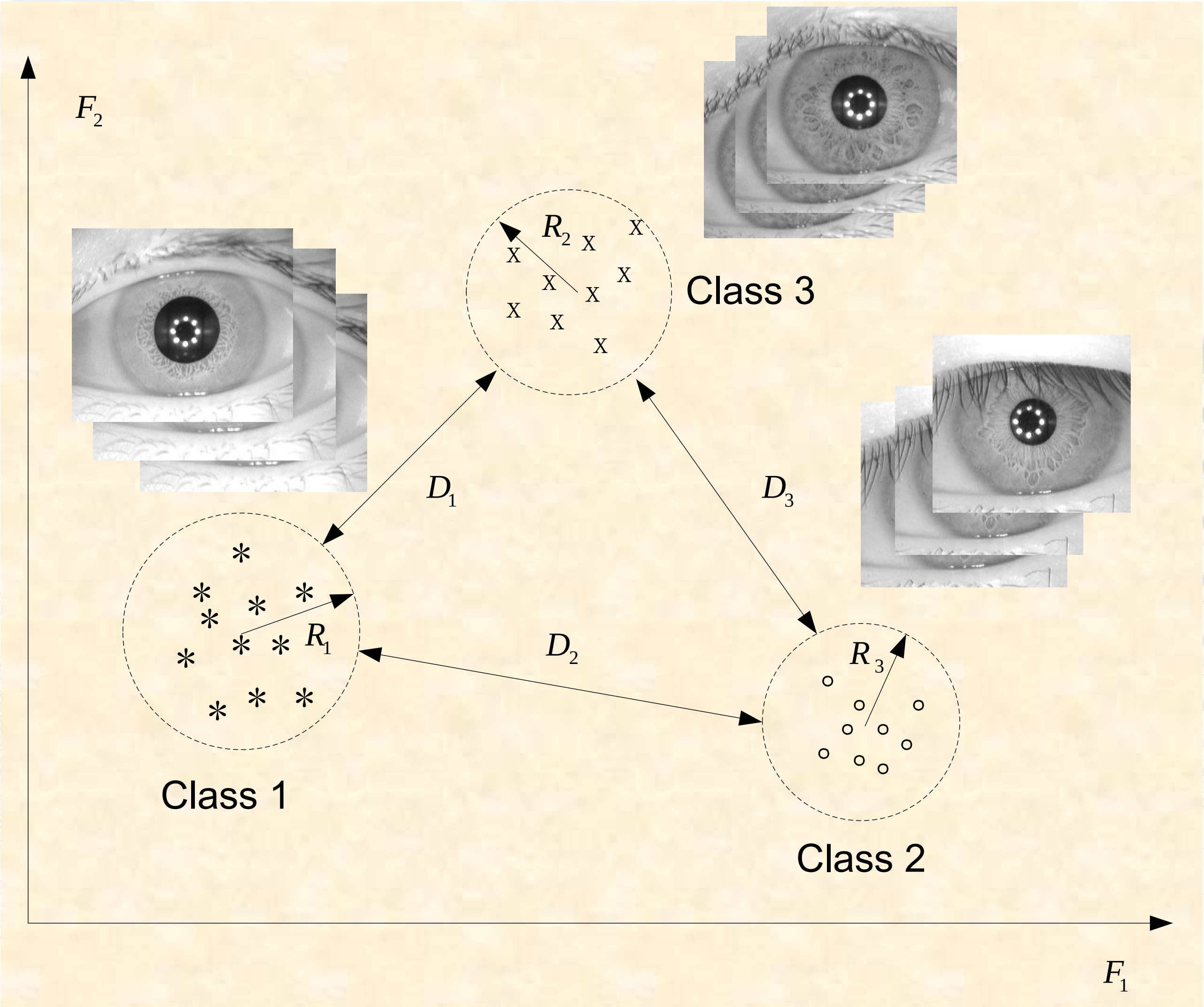
Outline of Talk

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

Flowchart of Iris Recognition

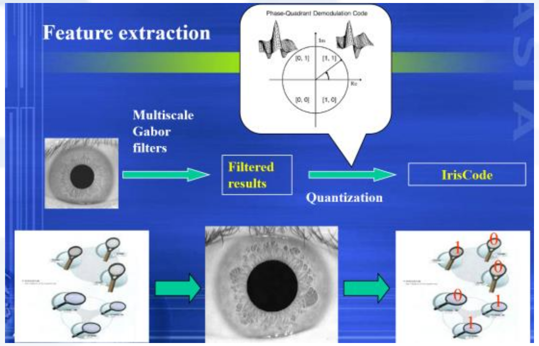


Objective of Iris Pattern Representation

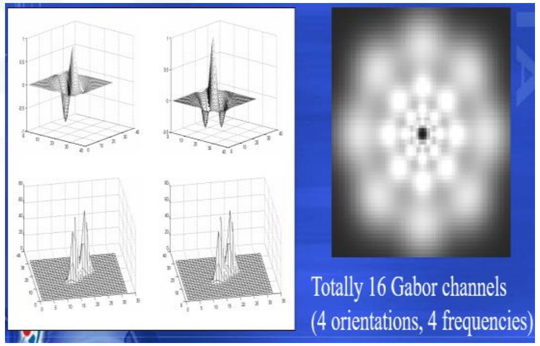


Minimize intra-class distance and maximize inter-class distance

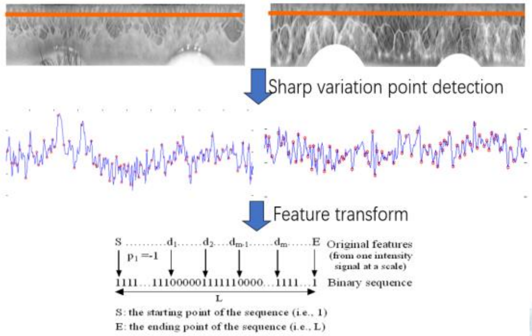
Iris Pattern Representation



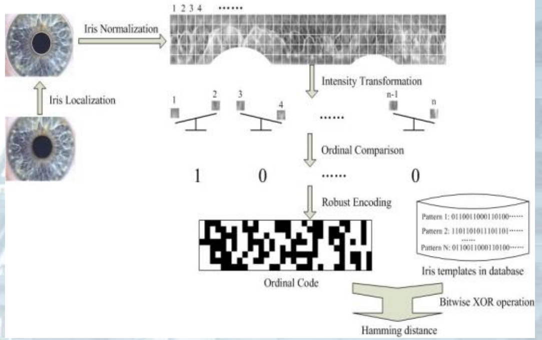
IrisCode (Daugman, PAMI1993)



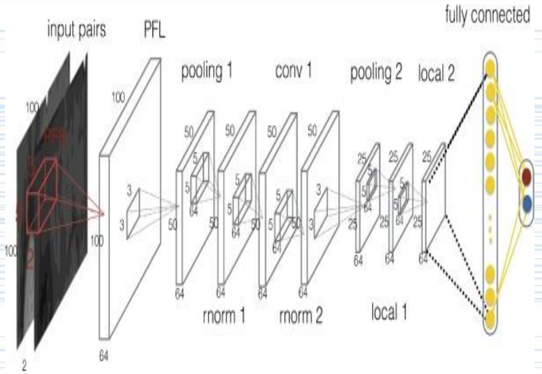
Gabor texture (Tan, PAMI2003)



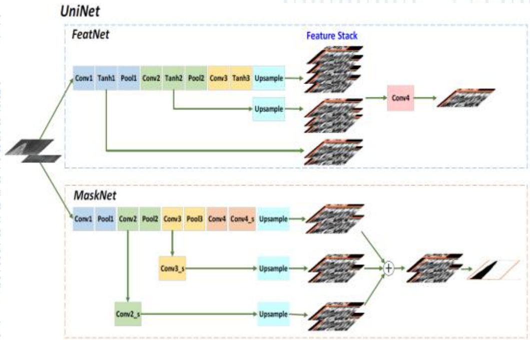
Local variations (Tan, TIP2004)



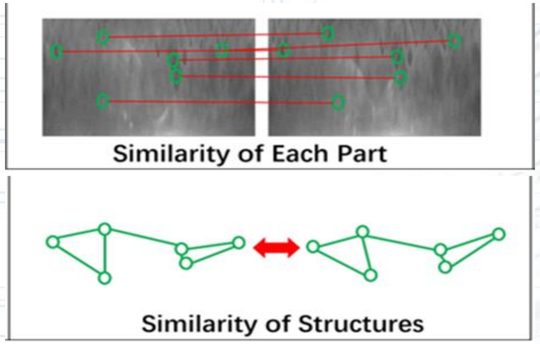
Ordinal measures (Tan, PAMI2009)



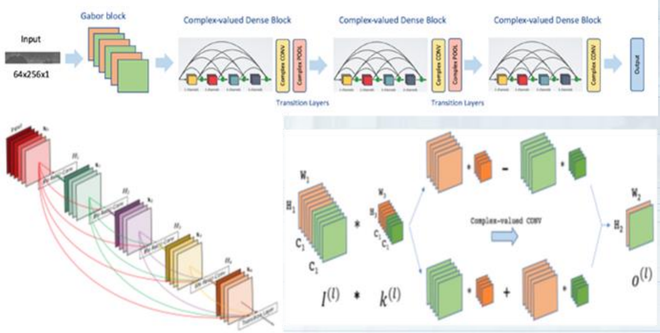
DeepIris (Tan, PRL2016)



UniNet (Kumar, ICCV2017)



Graph Representation (Tan, AAAI2020)

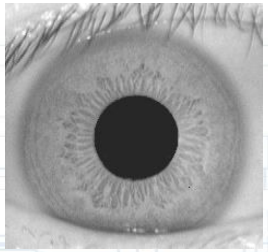


ComplexIrisNet (Nguyen, PAMI2022)

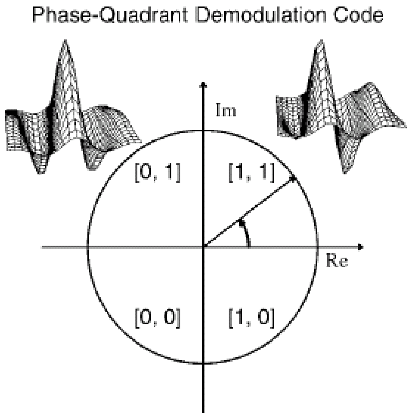
Daugman's Method: IrisCode

John Daugman

Feature extraction



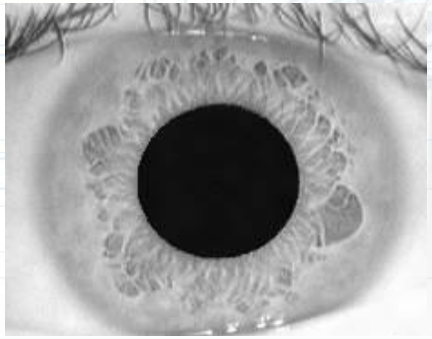
Multiscale Gabor filters

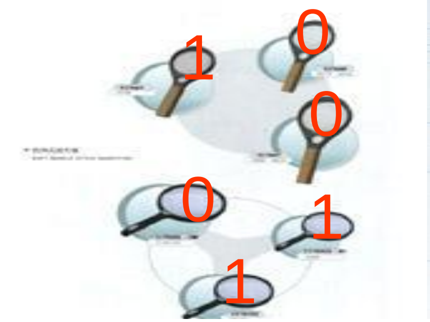


Filtered results

Quantization

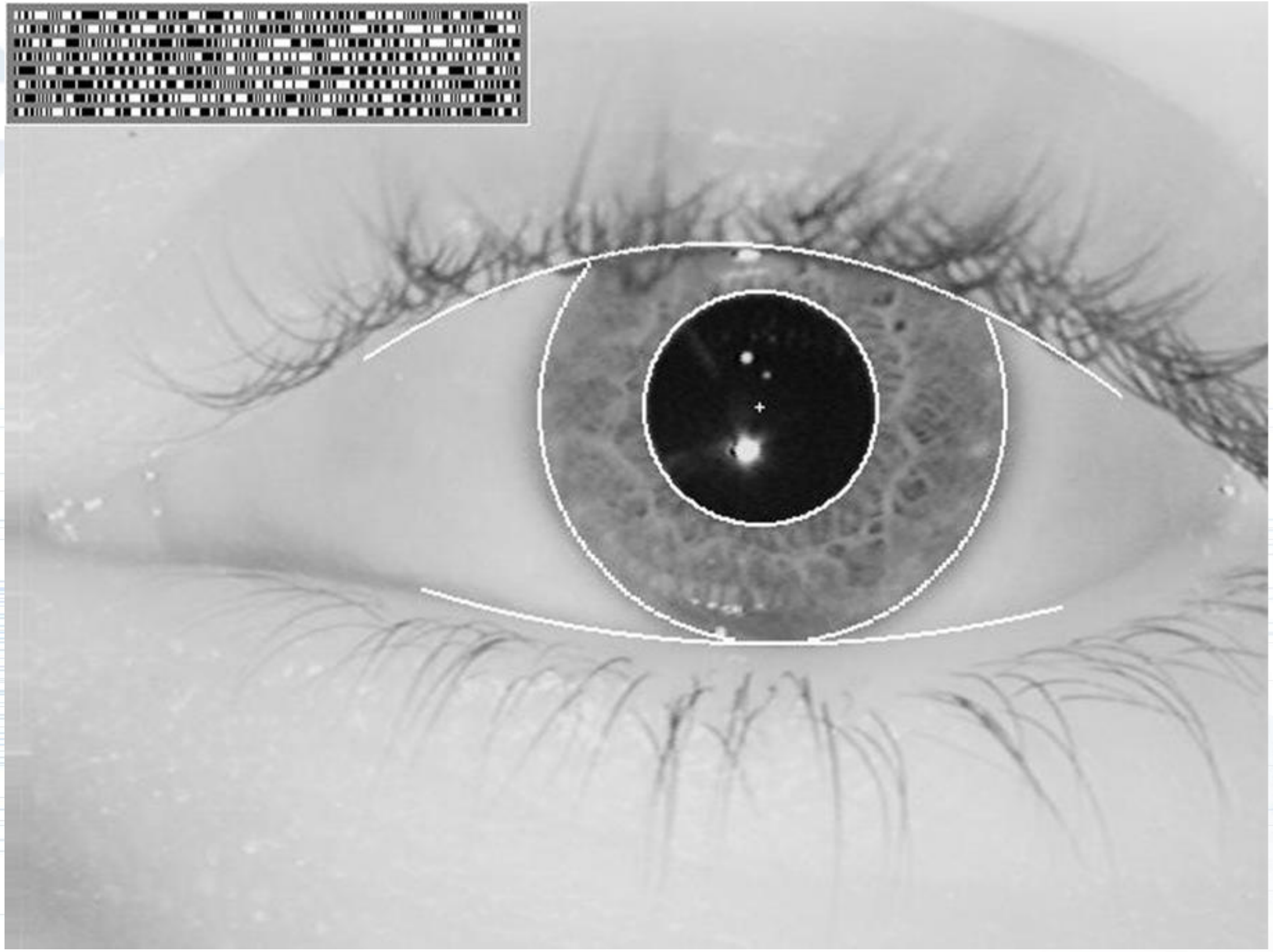
IrisCode



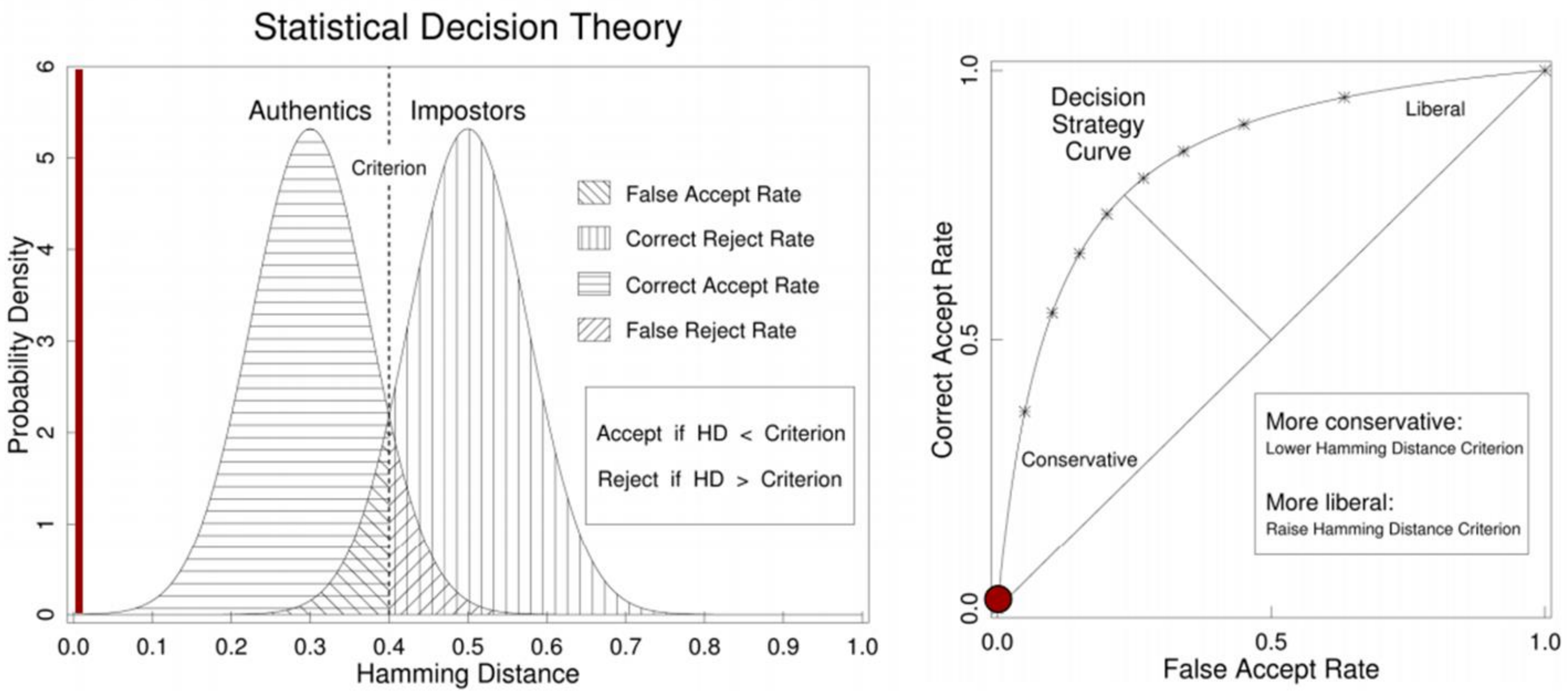


J. Daugman, High confidence visual recognition of persons by a test of statistical independence, IEEE Trans. on Pattern Analysis and Machine Intelligence (***T-PAMI***), vol.15, no.11, pp.1148-1161, 1993.

Examples of IrisCodes



Distribution of Hamming Distances and Decision

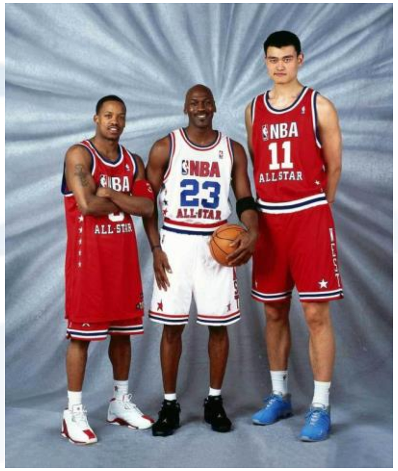


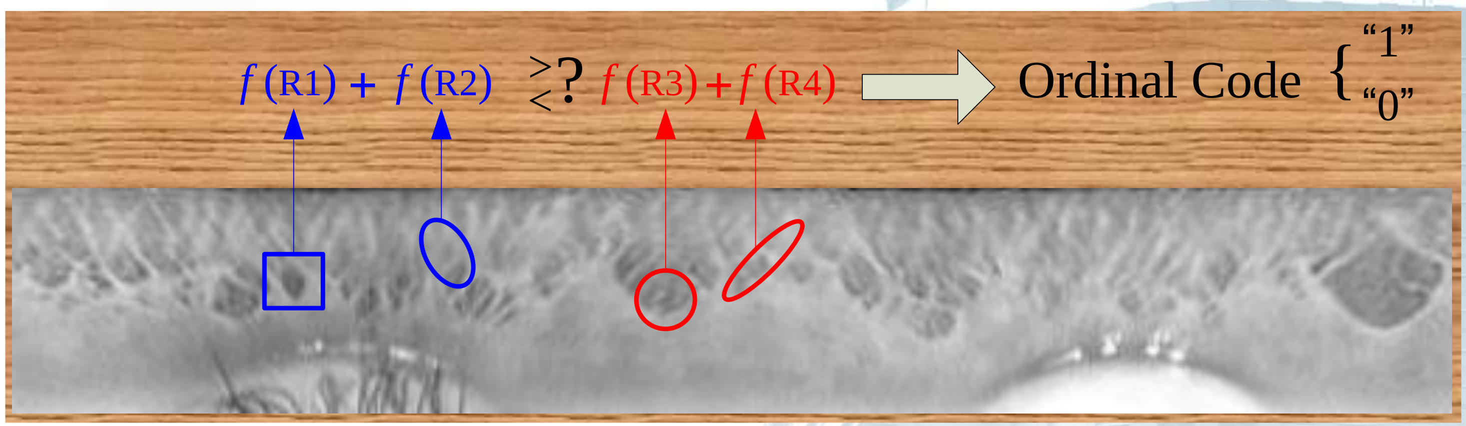
(from John Daugman)

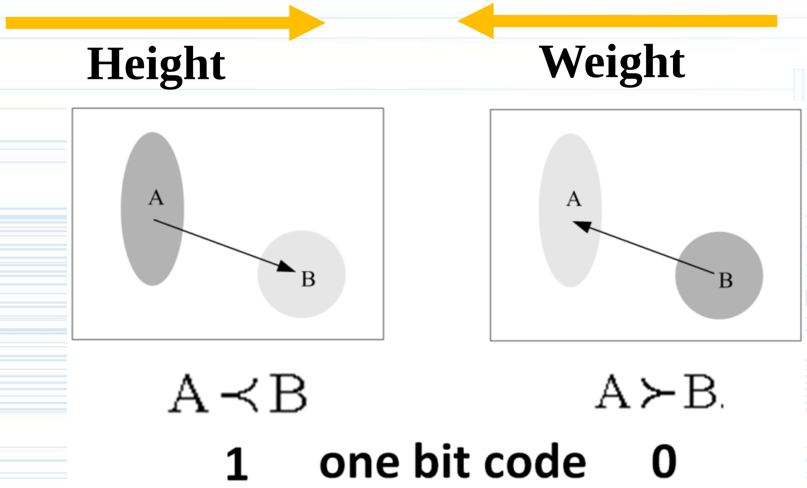
Two Important Questions in Iris Recognition

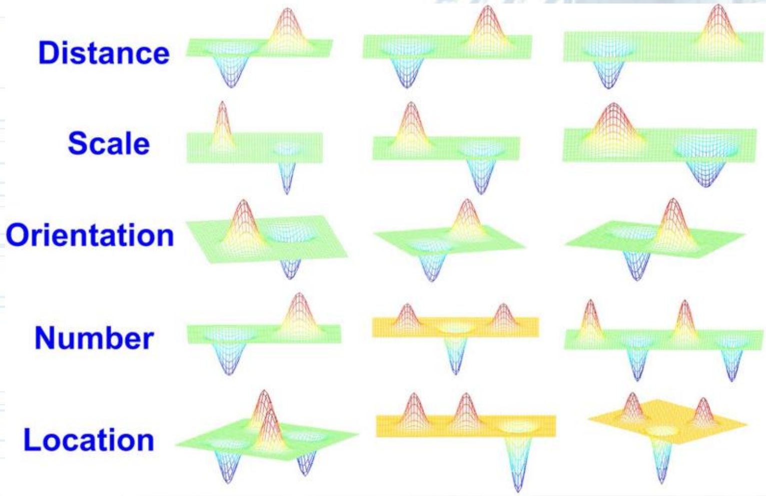
- Why do some iris recognition algorithms perform better (e.g., why is Daugman's IrisCode so good)?
- How to do better than the best (e.g., can we possibly outperform Daugman's IrisCode)?

Ordinal Measures for Iris Pattern Recognition



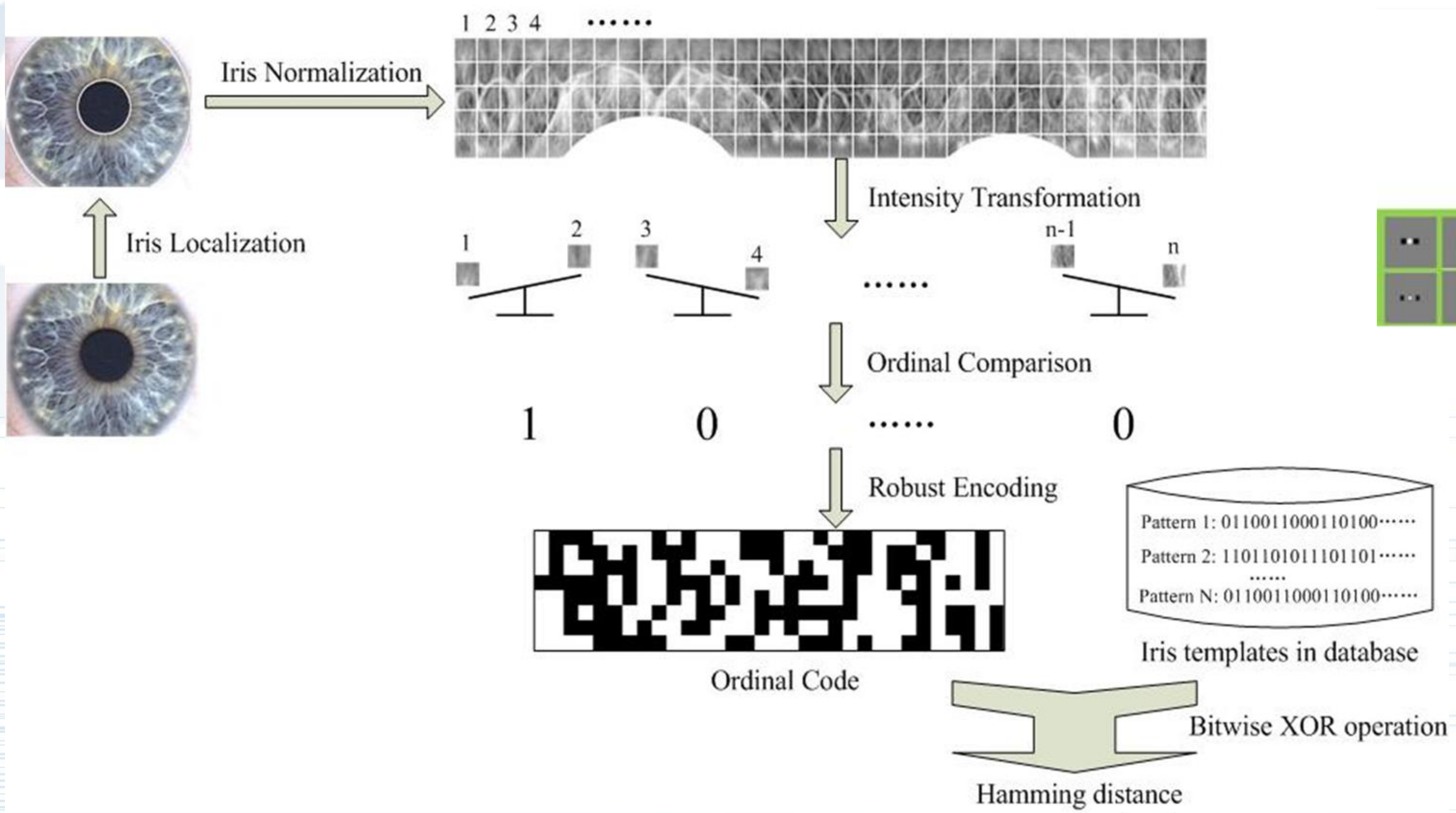


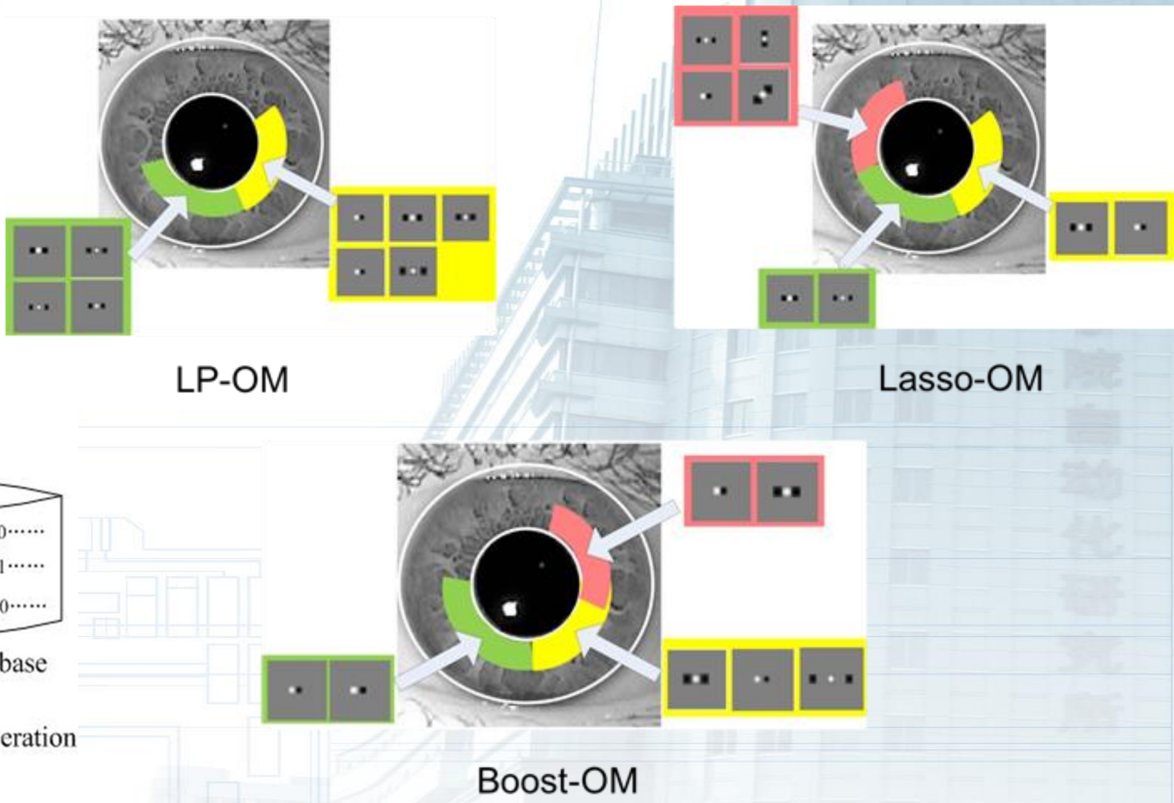




Zhenan Sun and Tieniu Tan, "Ordinal Measures for Iris Recognition", IEEE Transactions on Pattern Analysis and Machine Intelligence (***T-PAMI***), Vol. 31, No. 12, 2009, pp. 2211 - 2226.

Ordinal Measures for Iris Pattern Recognition

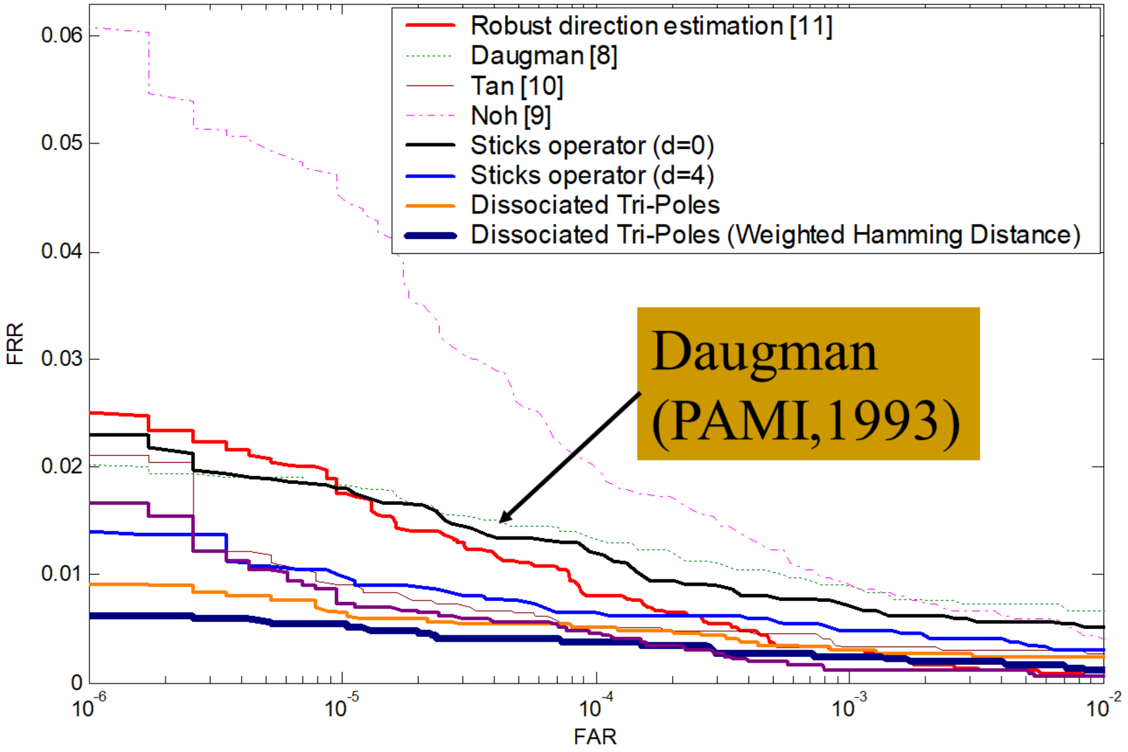


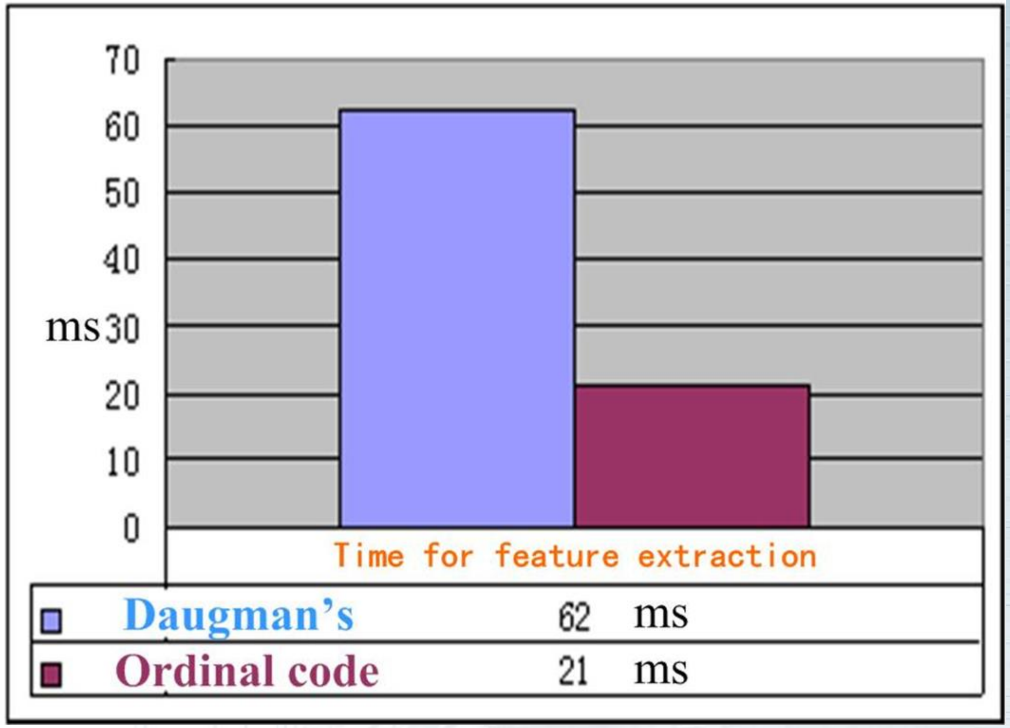


Ordinal code extraction **Ordinal feature selection**

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

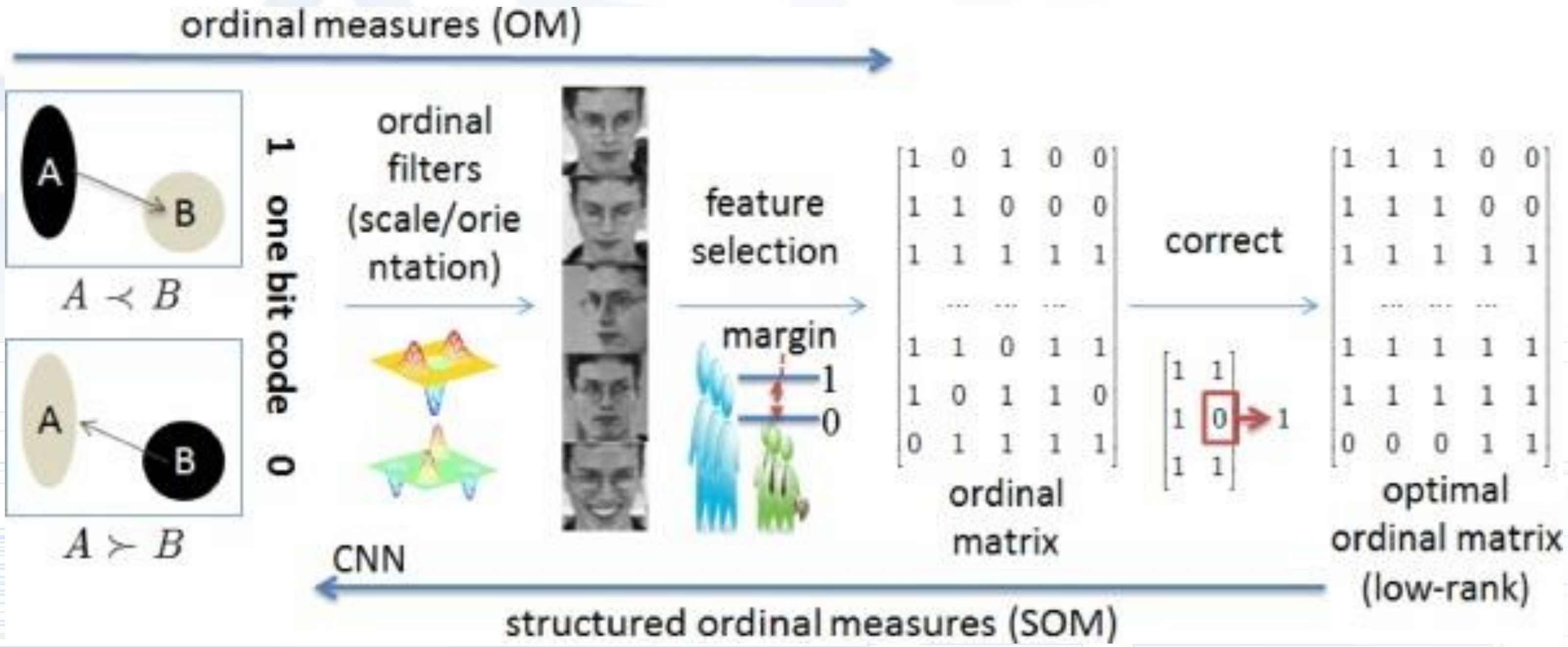




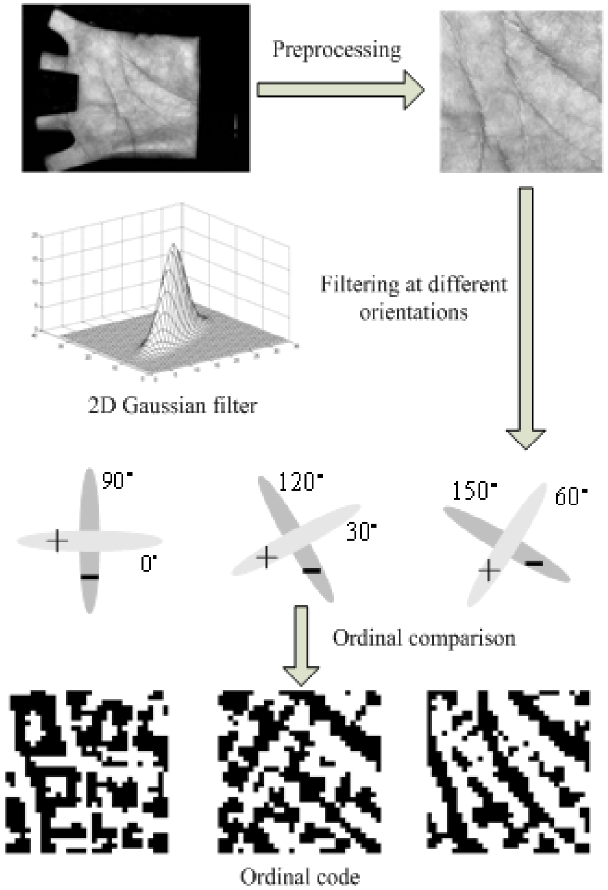
High accuracy and low computational cost

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



Structured ordinal measures for face recognition

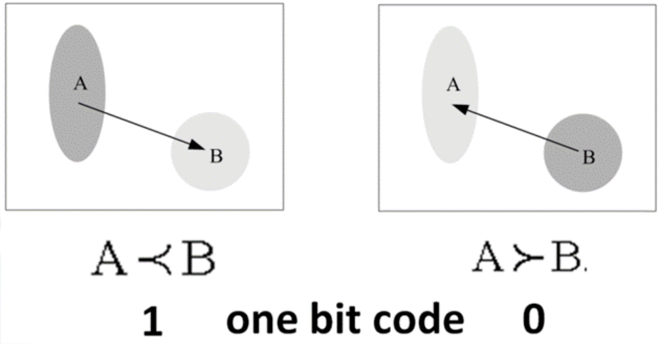


Ordinal feature selection for palmprint recognition

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.

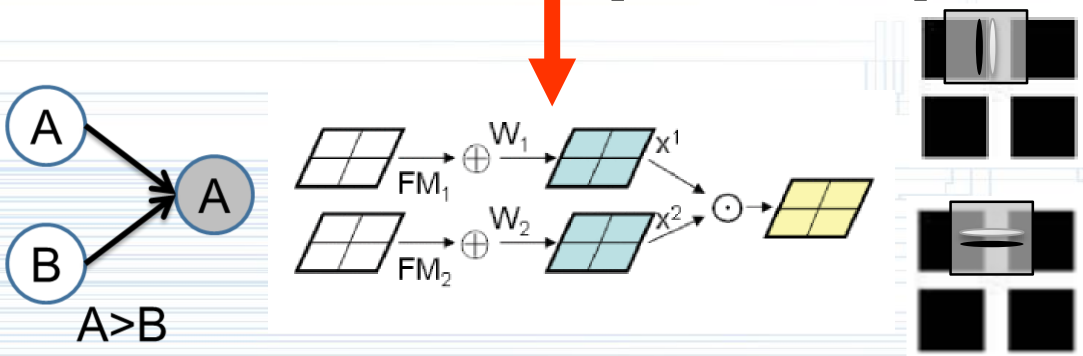
Ran He, Tieniu Tan, Larry Davis, Zhenan Sun, "Learning structured ordinal measures for video based face recognition", Pattern Recognition (***PR***), Vol. 75, 2018, pp.4-14.

Light CNN for Face Recognition Inspired by Ordinal Measures

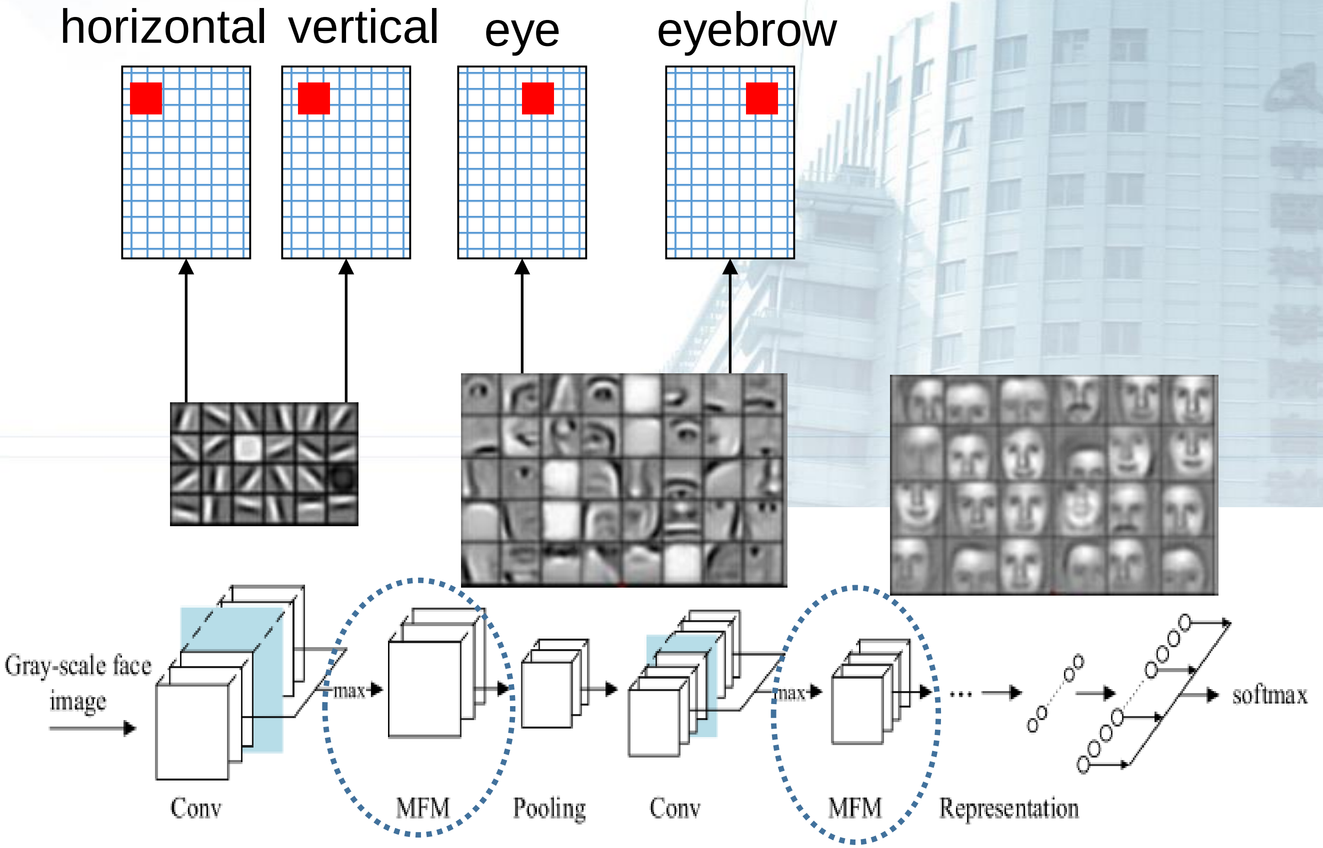


Ordinal measures

qualitative comparison



Max-feature-map (MFM)

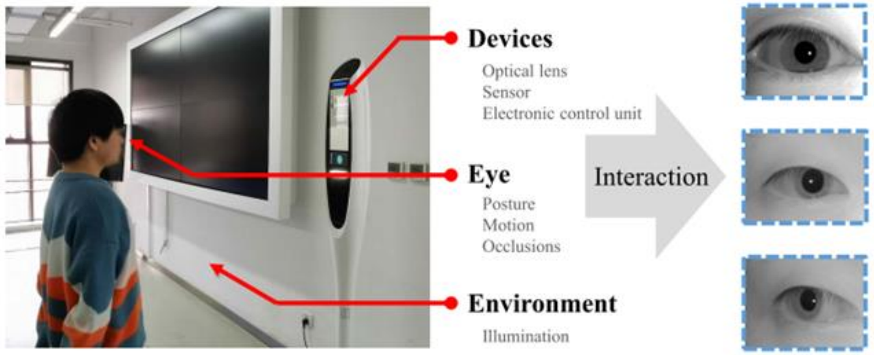


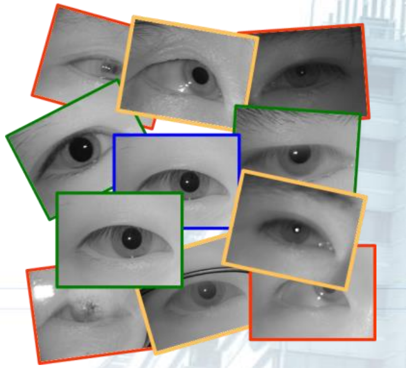
The structure of LightCNN

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.

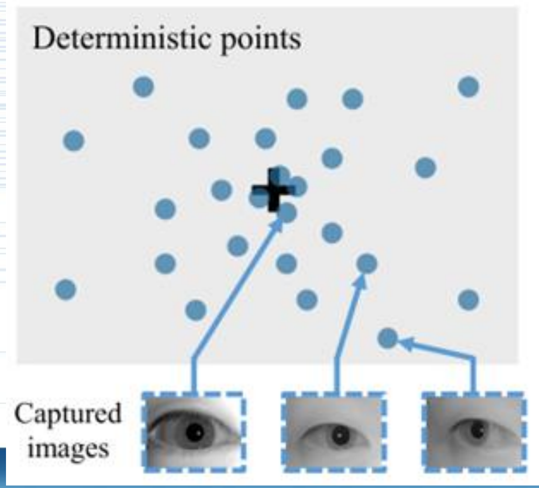
Uncertainty Learning in Iris Recognition

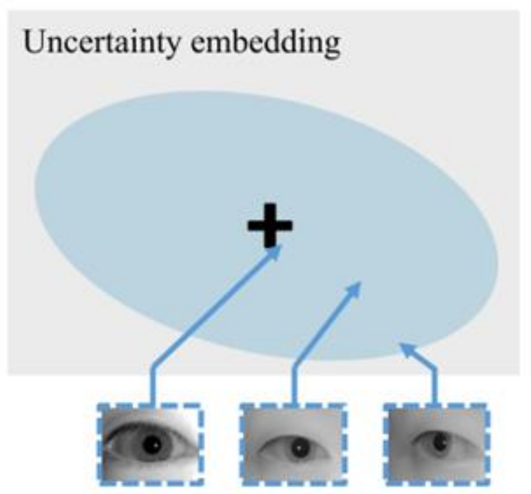
Interfering or uncertain factors always exist during iris image acquisition. This means that an iris image should ideally be represented using a probabilistic distribution rather than a deterministic point in the feature space.





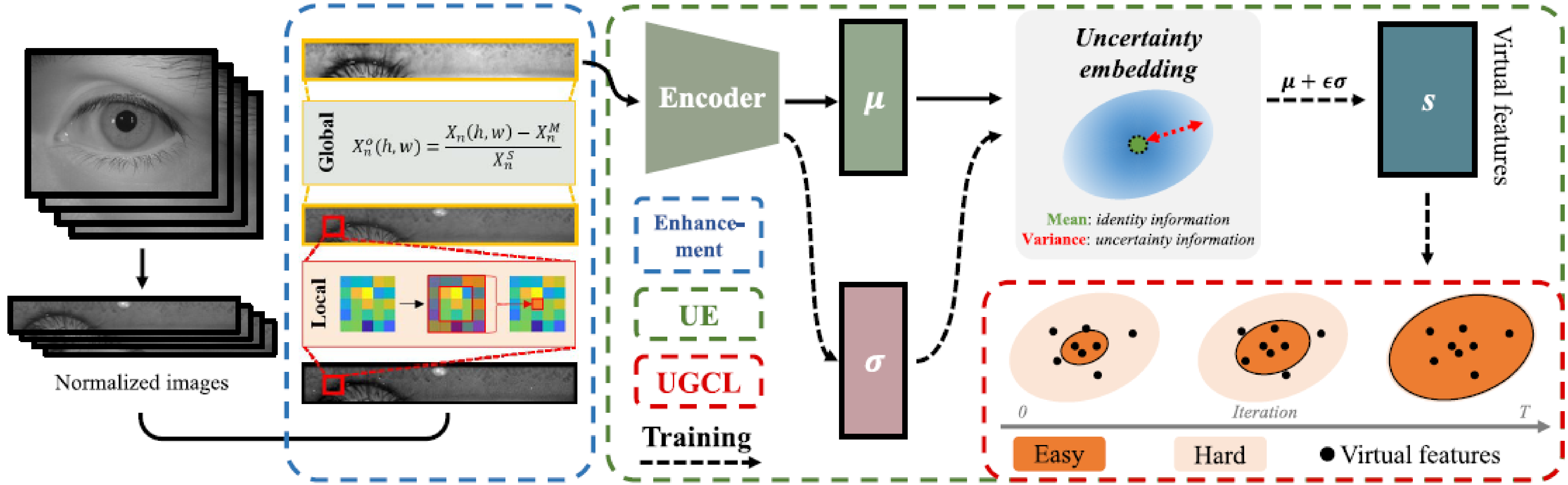
Intra-class variations of Iris Images





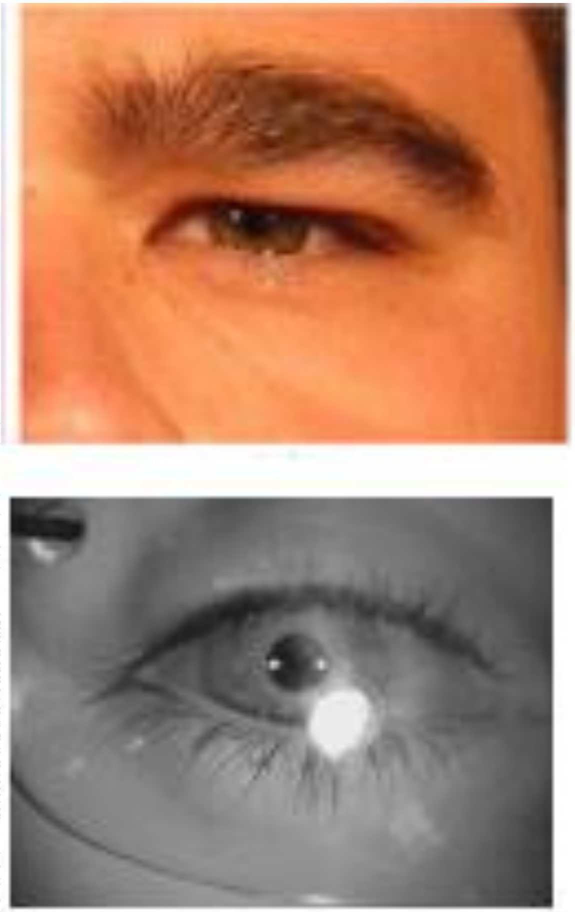
Learning Uncertainty Embedding for Iris Recognition

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

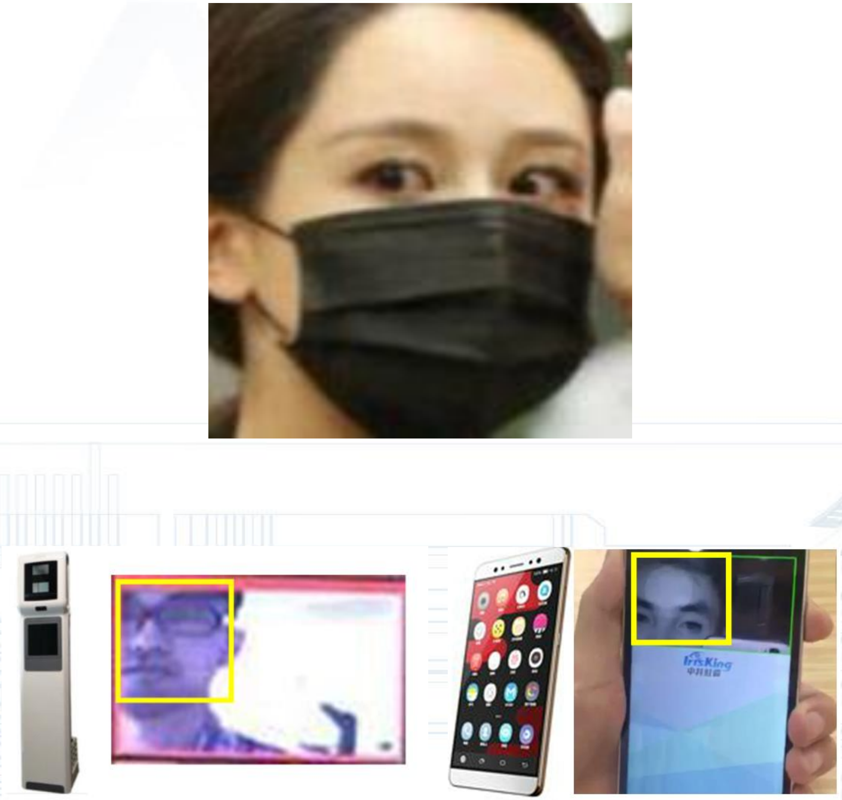


Jianze Wei, et al., Towards More Discriminative and Robust Iris Recognition by Learning Uncertain Factors, IEEE Transactions on Information Forensics and Security (***TIFS***), vol. 17, pp. 865-879, 2022.

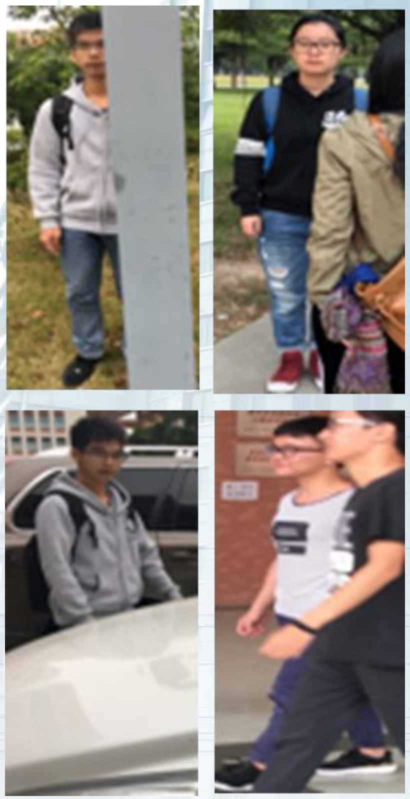
The Occlusion Problem in Biometrics



Iris



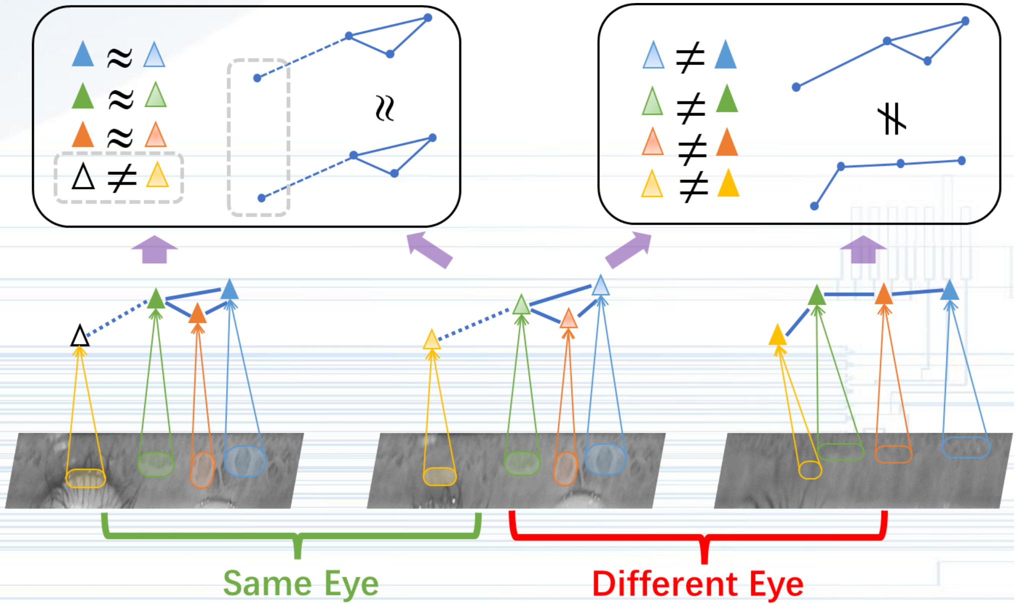
Face

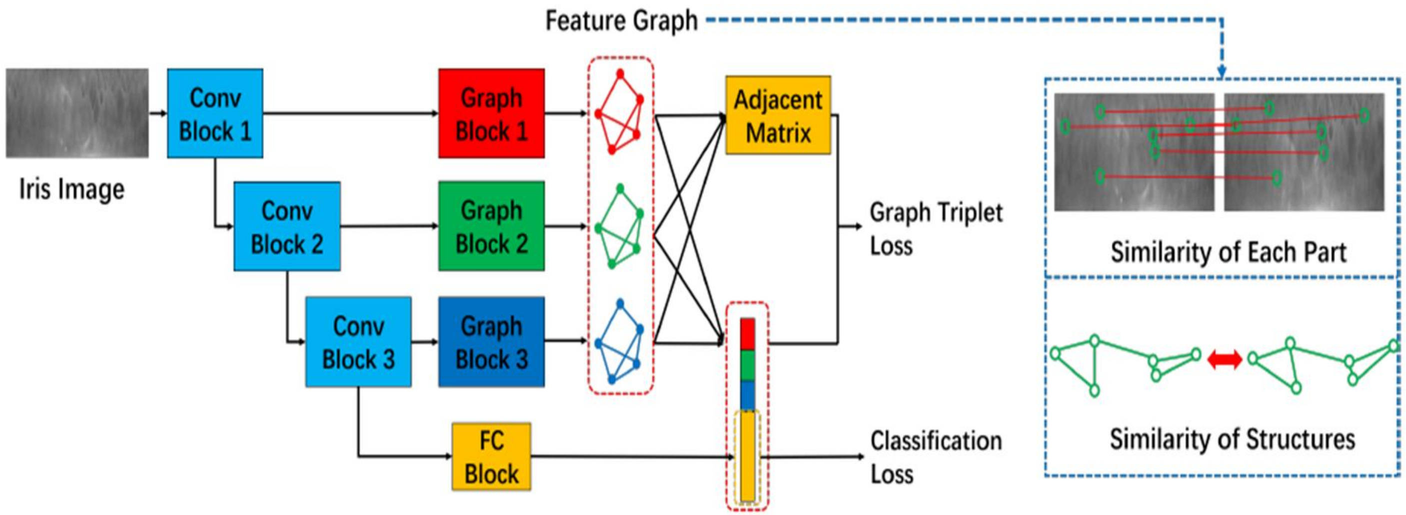


Re-ID

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





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.

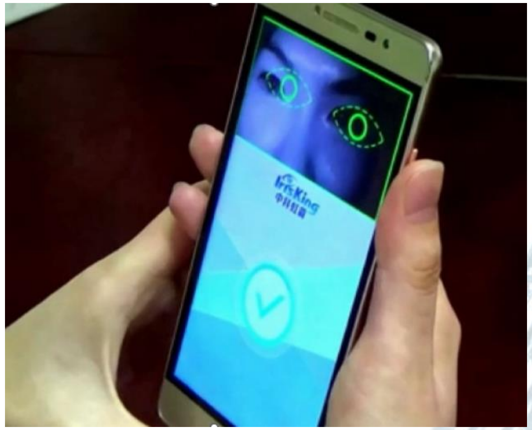
Outline of Talk

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

Applications of Iris Recognition


Coal miner attendance


Banking


Mobile payment


Public Security


Border control

Social welfare


Missing children identification


Pet care

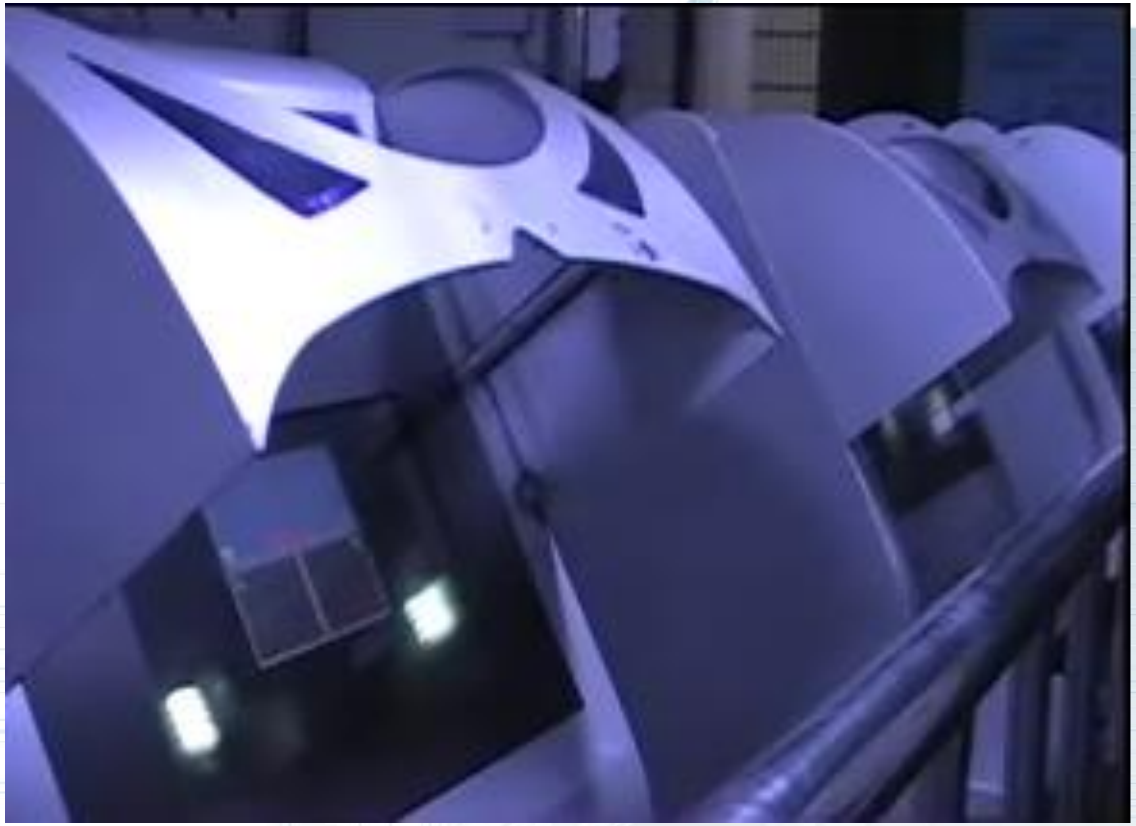
Iris Recognition for Social Welfare

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.

Mobile devices with iris recognition have been provided to refugees for efficient delivery of assistance.

Iris Recognition for Social Welfare

Iris Recognition for Coal Miner Identification

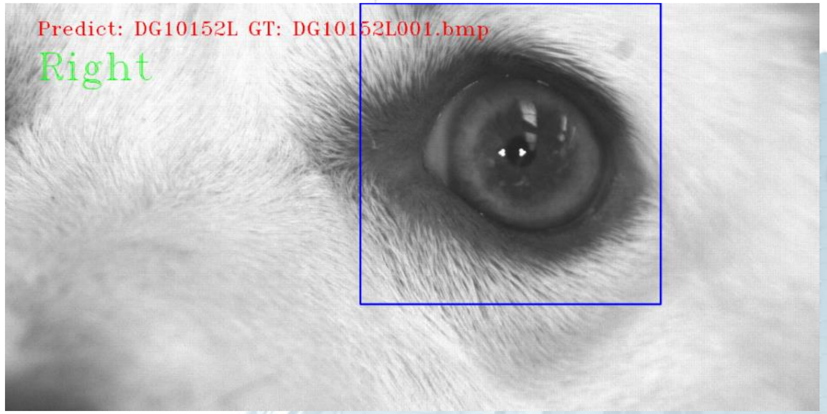


Our technology has been in routine use in many coal mines across China.

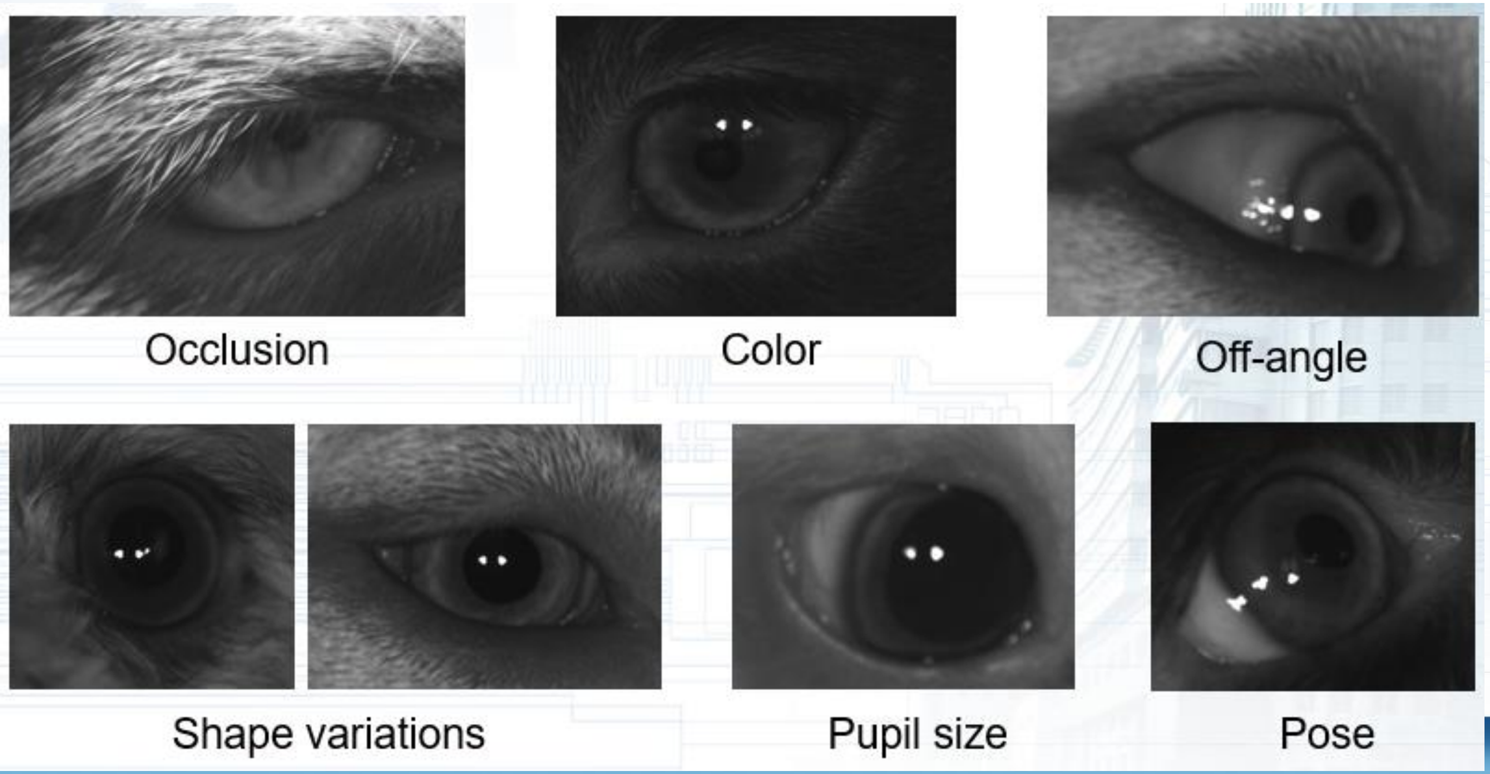
Iris Recognition for Animal Identification

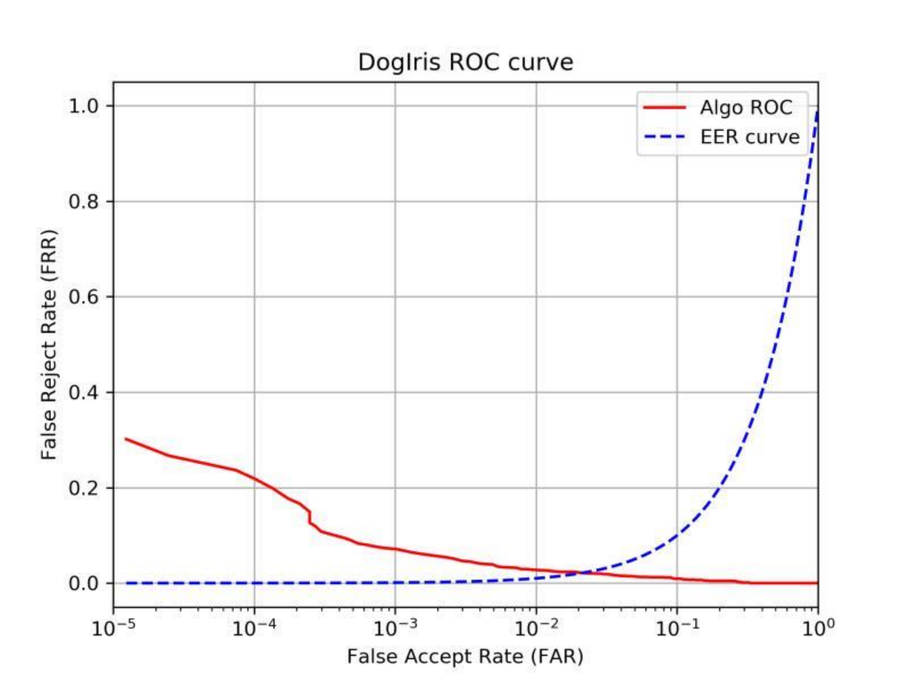
Iris Recognition of Dogs

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

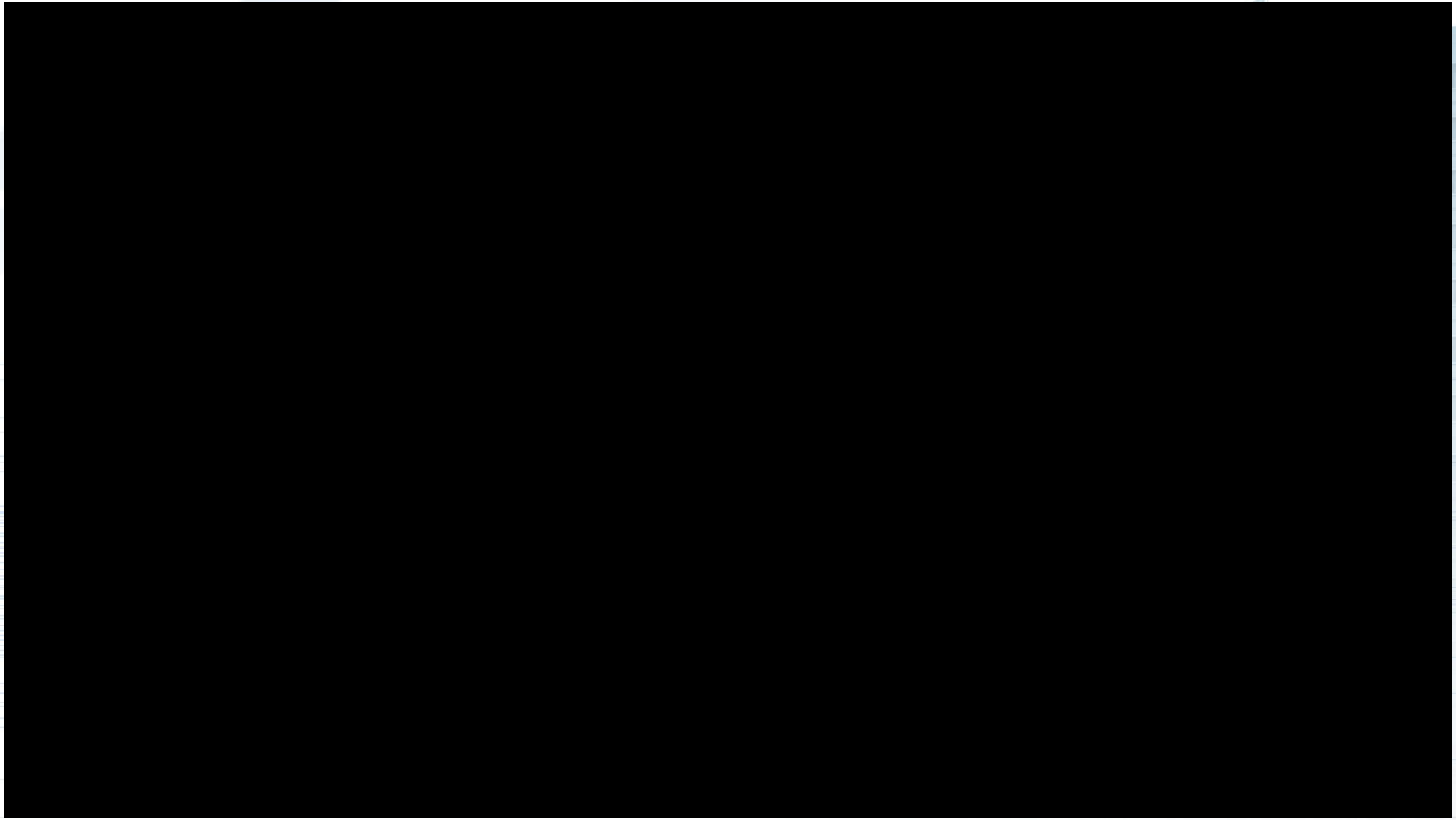


EER=0.9%, FRR=7%@FAR=0.1%，50fps





Iris Recognition of Dogs



Outline of Talk

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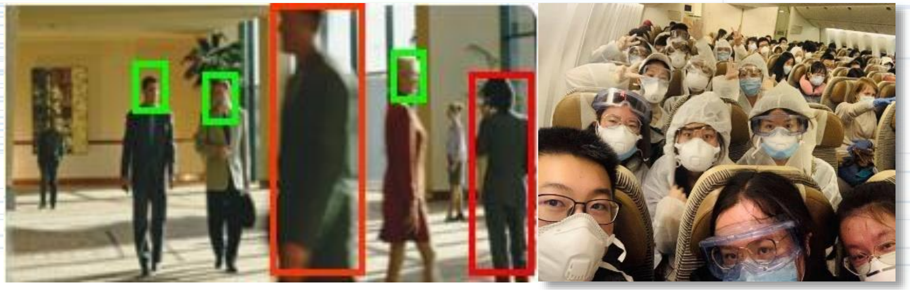
  - ✓ Iris image acquisition
  - ✓ Iris image preprocessing
  - ✓ Iris pattern recognition
- Applications of Iris Recognition
- Challenges and Future Directions

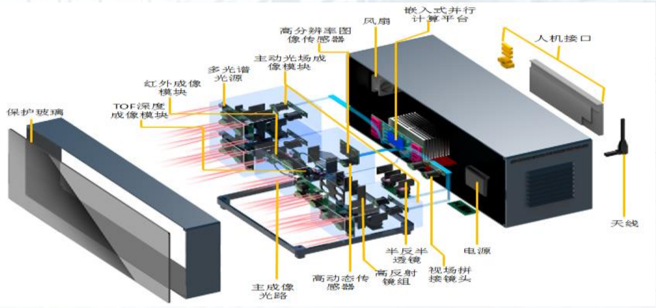
Challenges of Iris Recognition

1. Constraints on users during iris image acquisition



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

VS

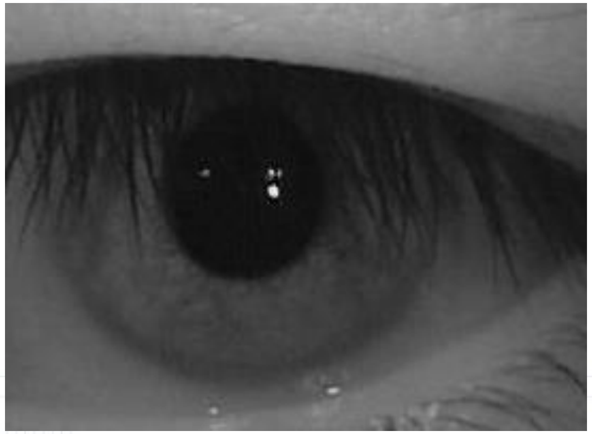


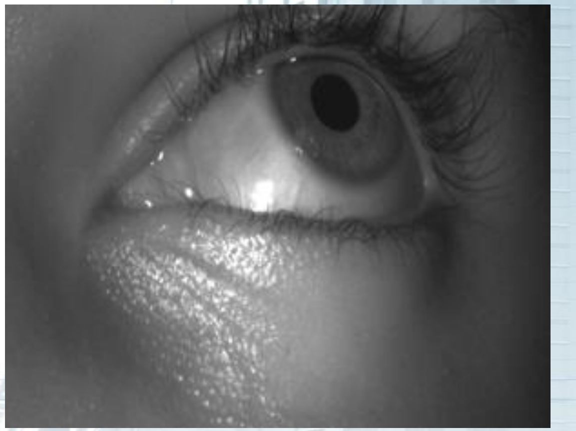
Fixed optics settings of iris sensors

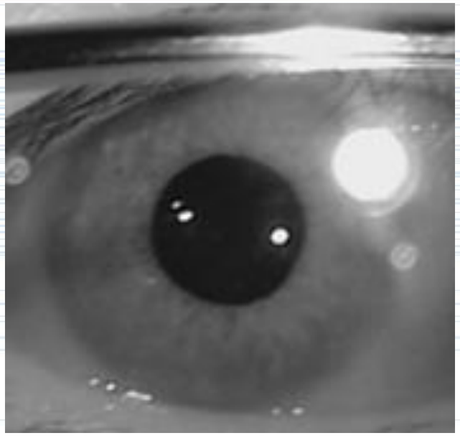
Challenges of Iris Recognition

2. Deteriorated performance on poor quality iris images


Eyelids


Eyelashes


Off-angle

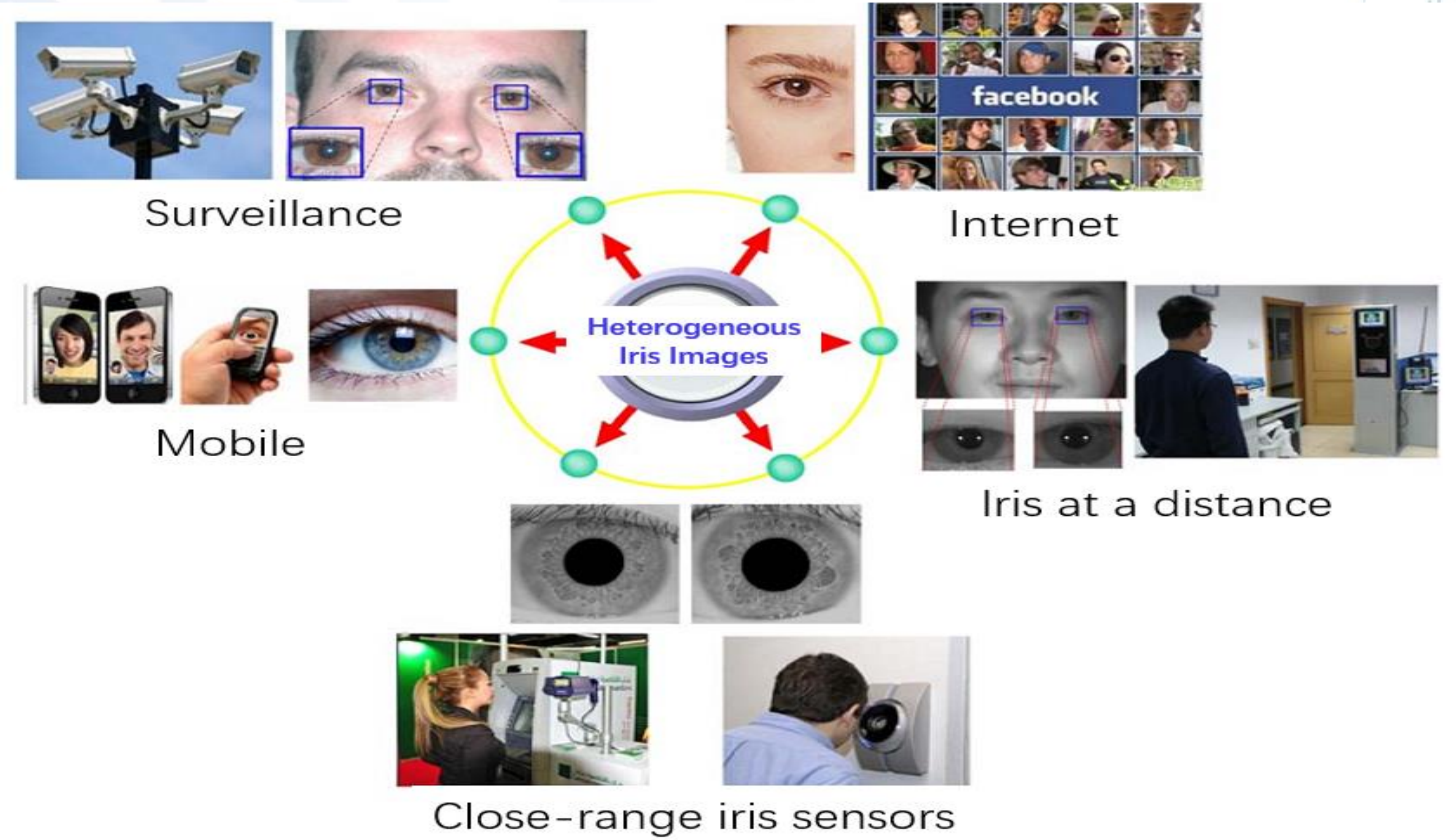

Specular reflections


Motion blur


Deformation

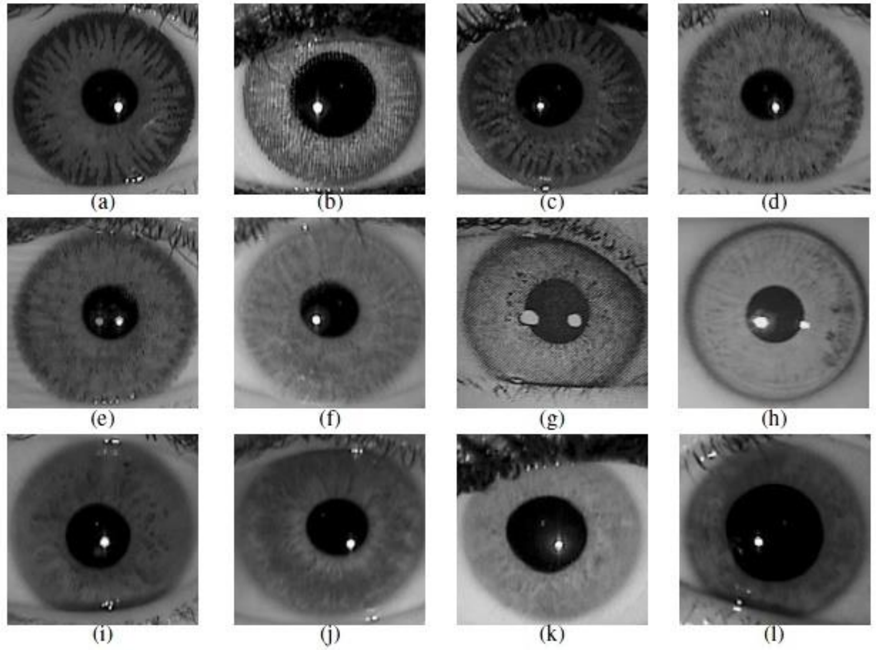
Challenges of Iris Recognition

3. Recognition of heterogenous iris images



Challenges of Iris Recognition

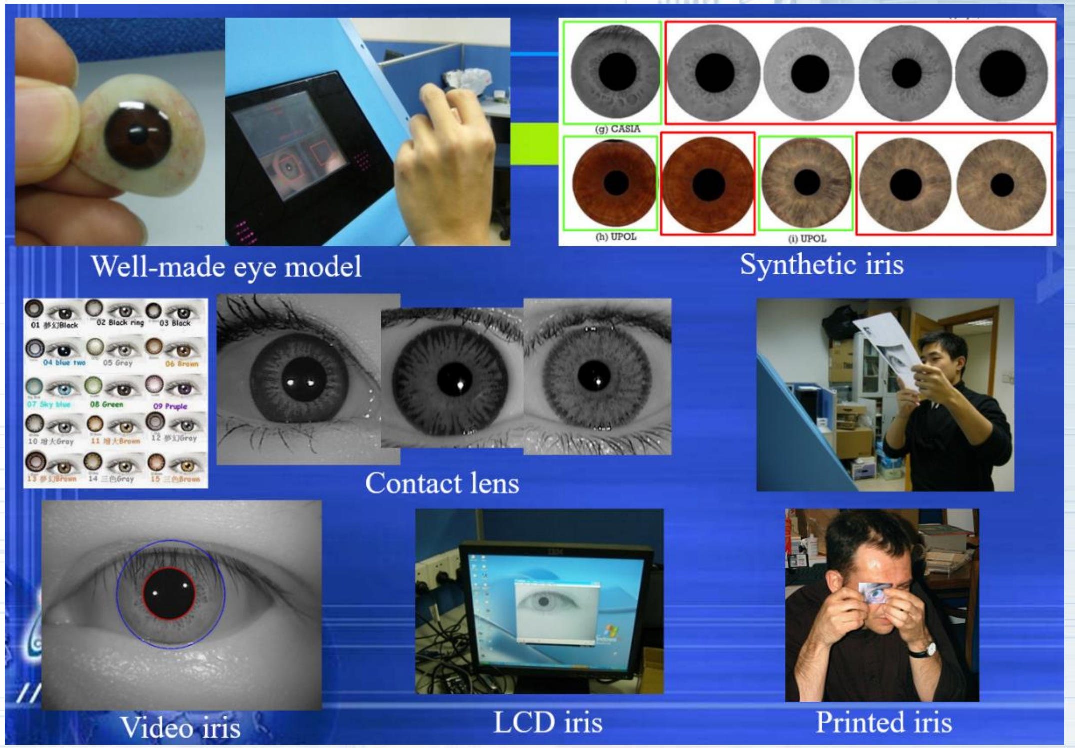
4. Unpredictable iris spoof attacks



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

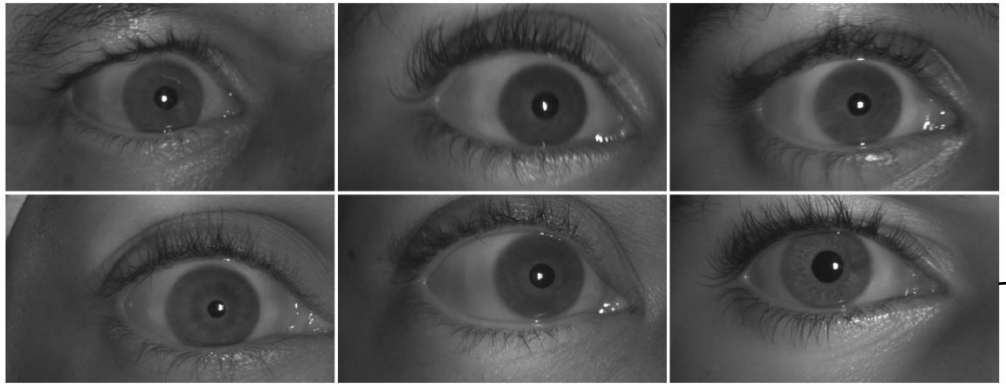
VS



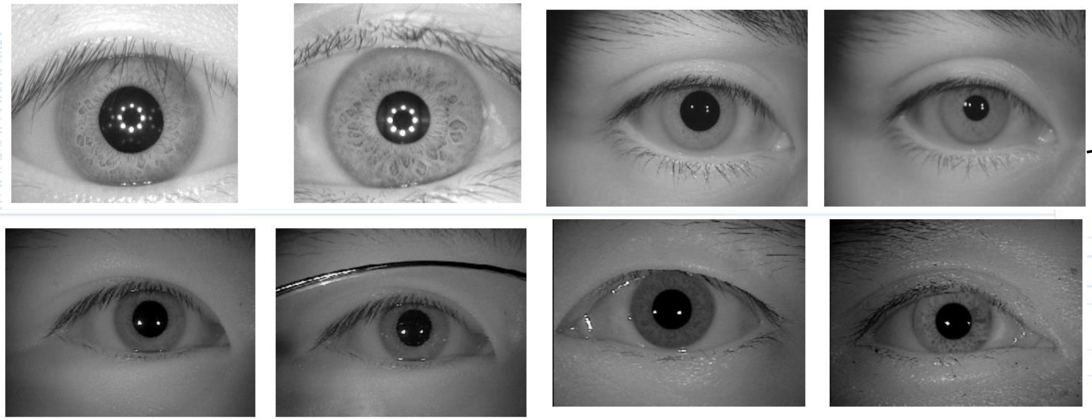
Unpredictable iris spoof attacks

Challenges of Iris Recognition

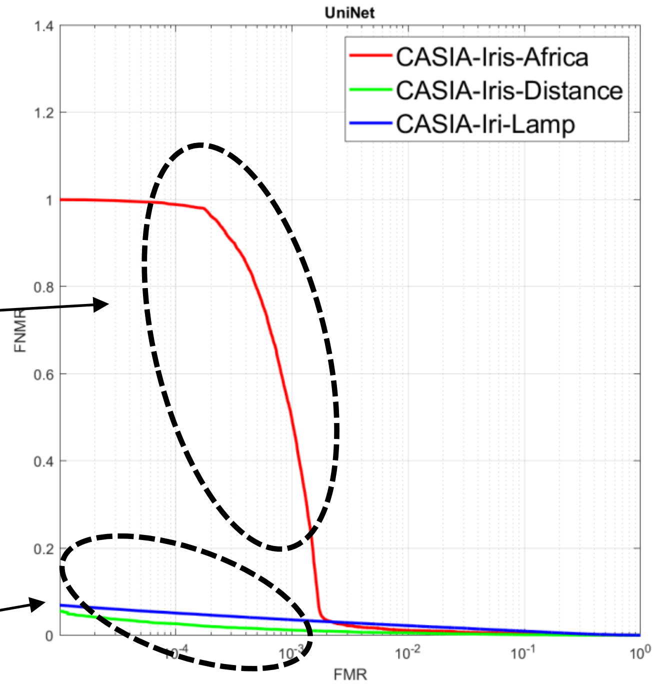
5. Category fairness (Ethnic generalizability)



CASIA-Iris-Africa



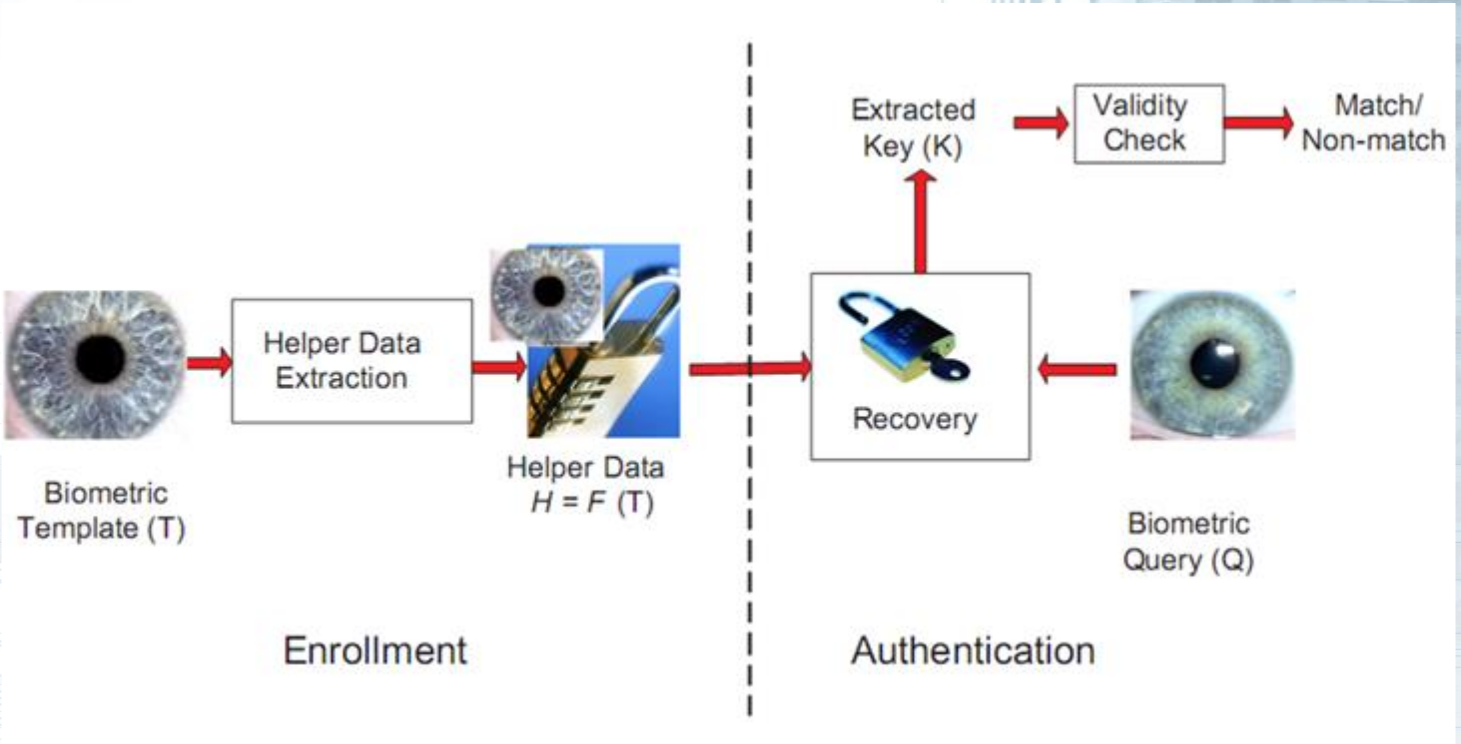
CASIA-Iris-Lamp and Distance



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%

Challenges of Iris Recognition

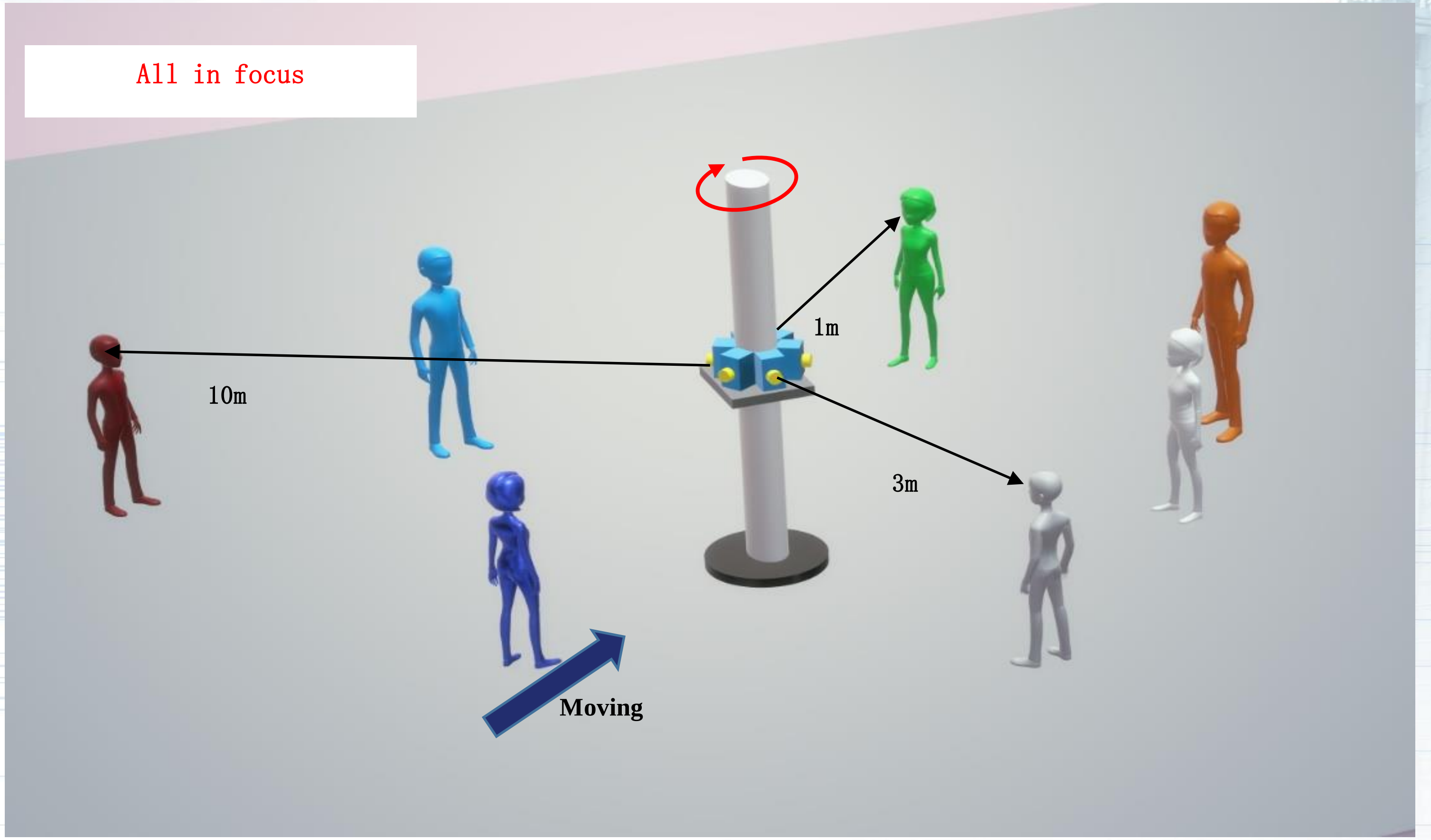
6. Privacy and Security



Future Directions of Iris Recognition

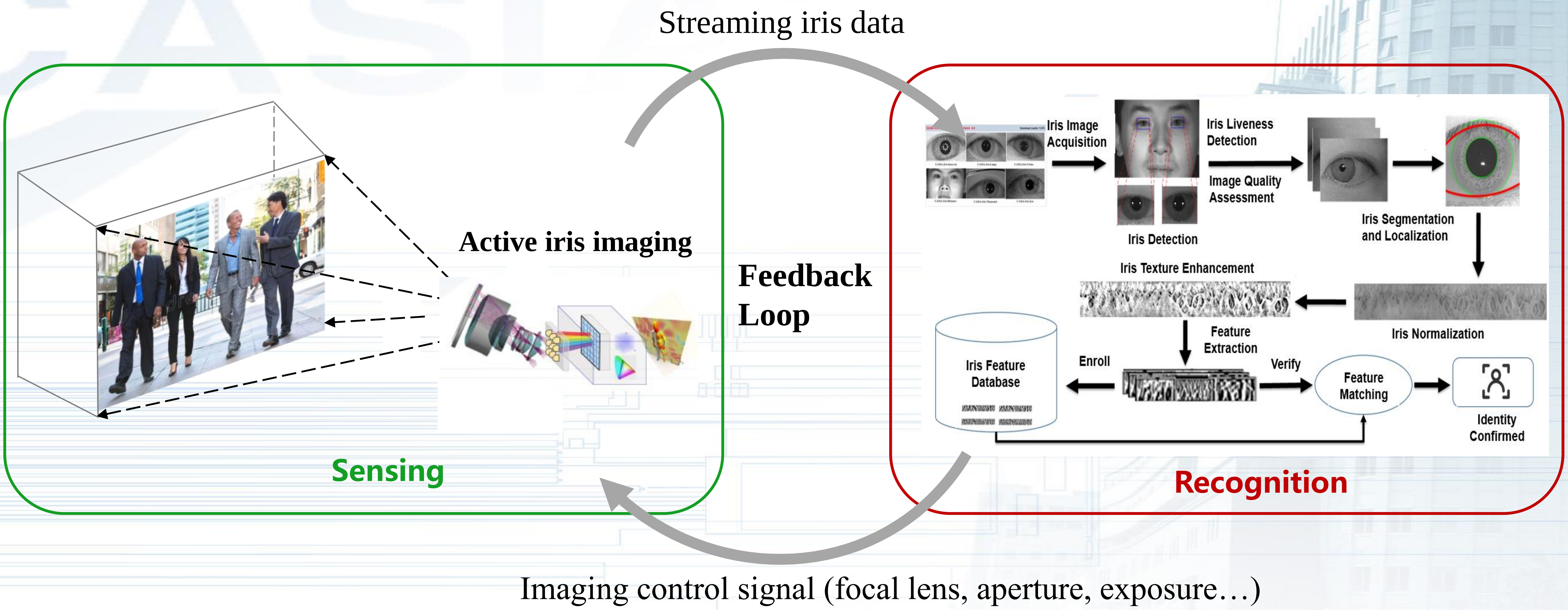
- High-throughput iris recognition in unconstrained environments

Simultaneous iris recognition of multiple people at a distance within seconds



Future Directions of Iris Recognition

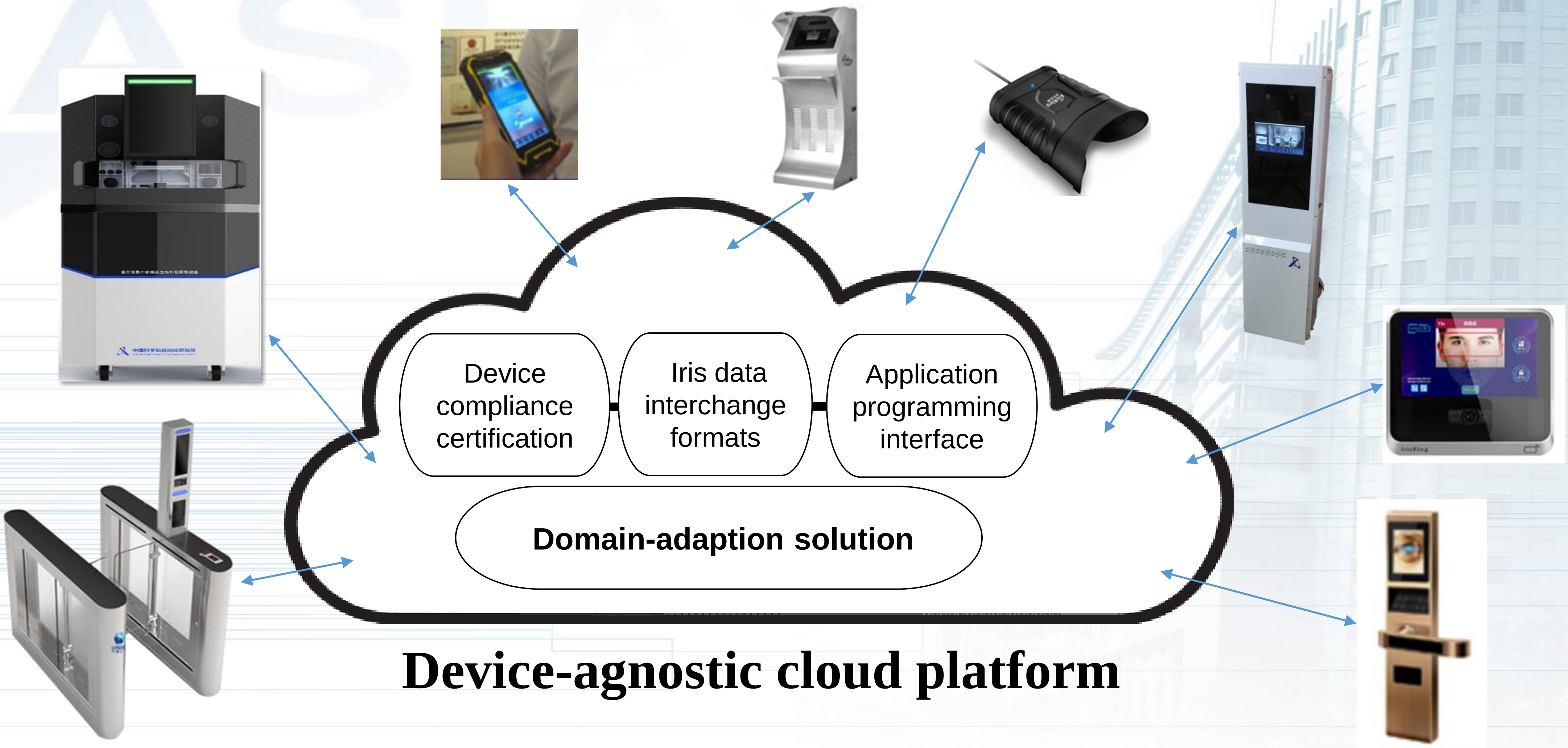
- Co-design and coordination of iris sensing and recognition



Hardware-software co-design	Acquisition and processing coordination

Future Directions of Iris Recognition

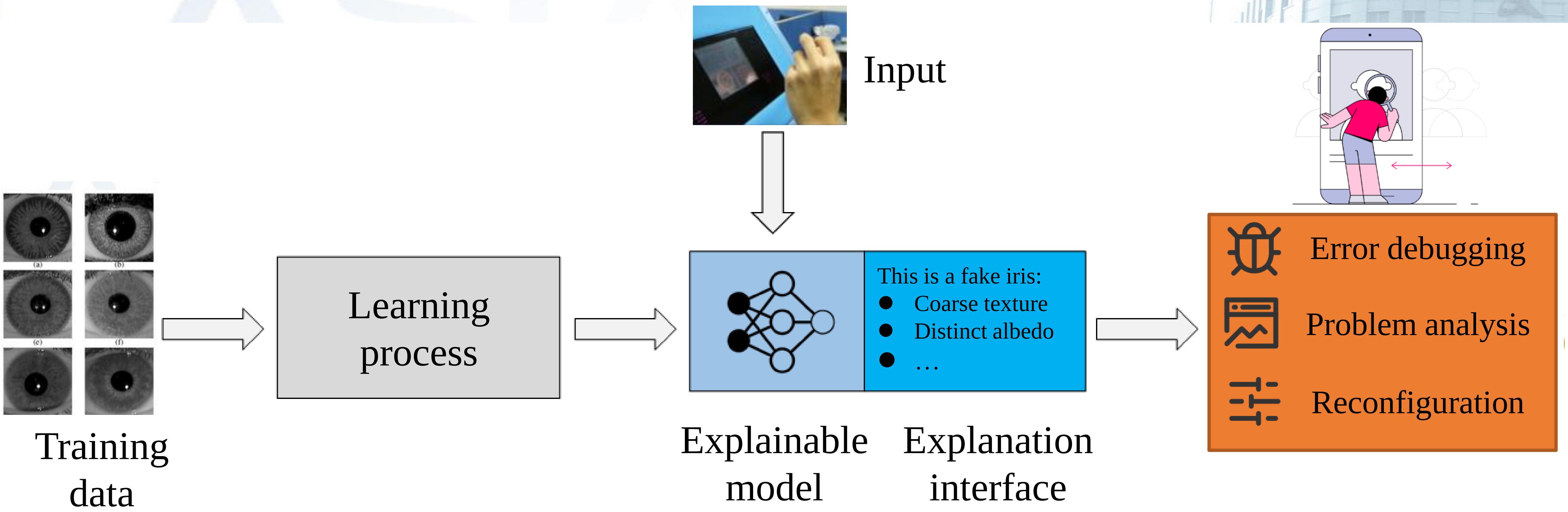
- Device-agnostic cloud service for heterogenous iris recognition



Device-agnostic cloud platform

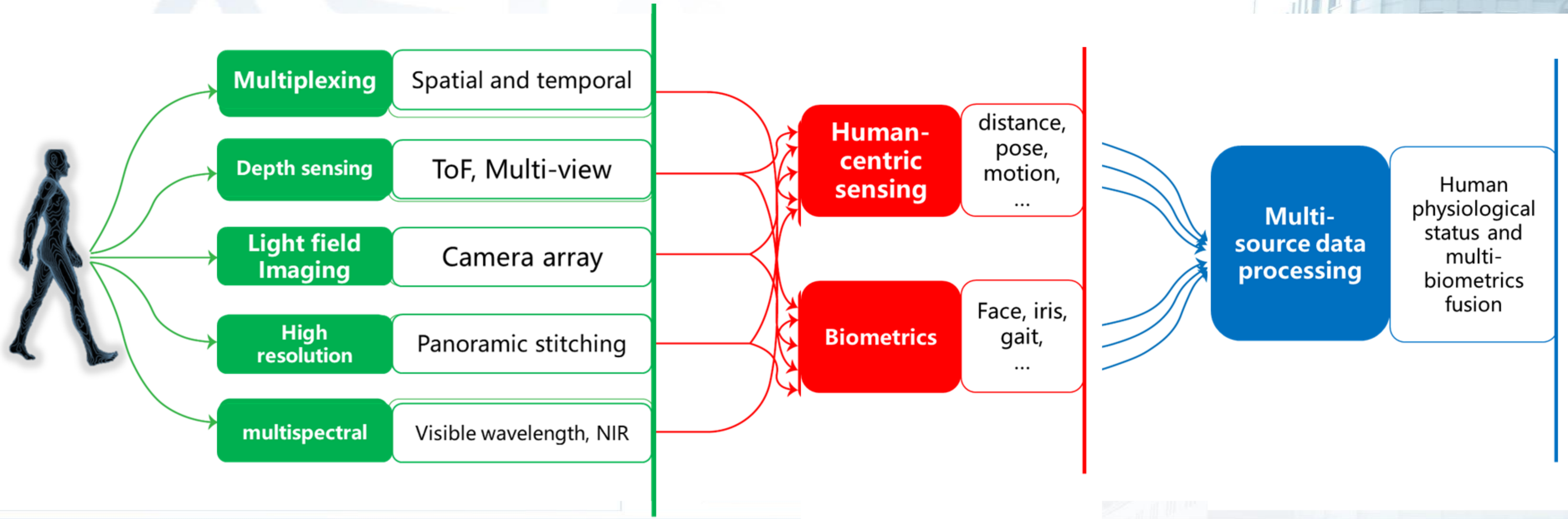
Future Directions of Iris Recognition

- Trustworthy iris liveness detection



Future Directions of Iris Recognition

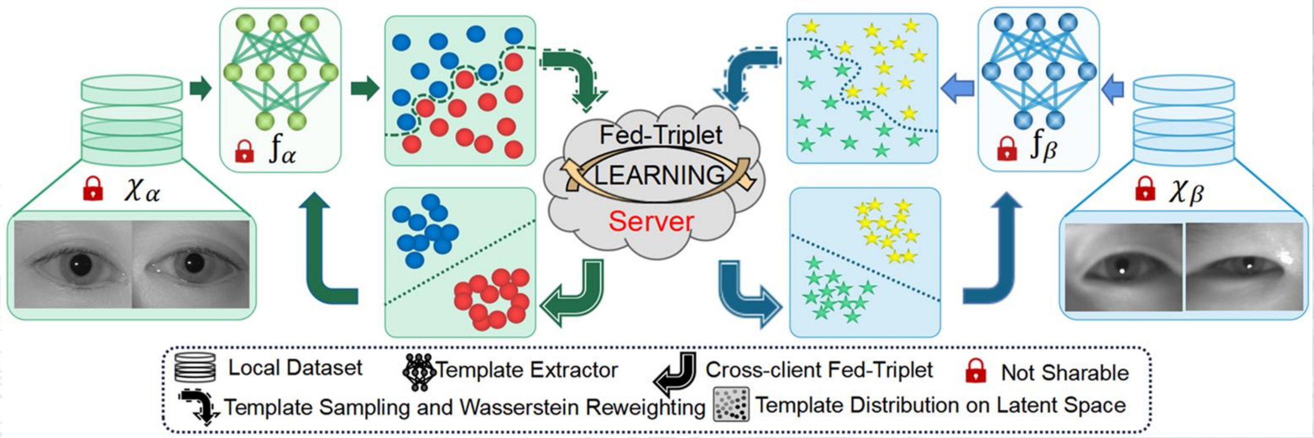
- Human-centric sensing and adaptive multi-biometrics fusion



Future Directions of Iris Recognition

- Privacy and security preserving decentralized applications

Distributed applications facing
a diversity of users, devices and environments

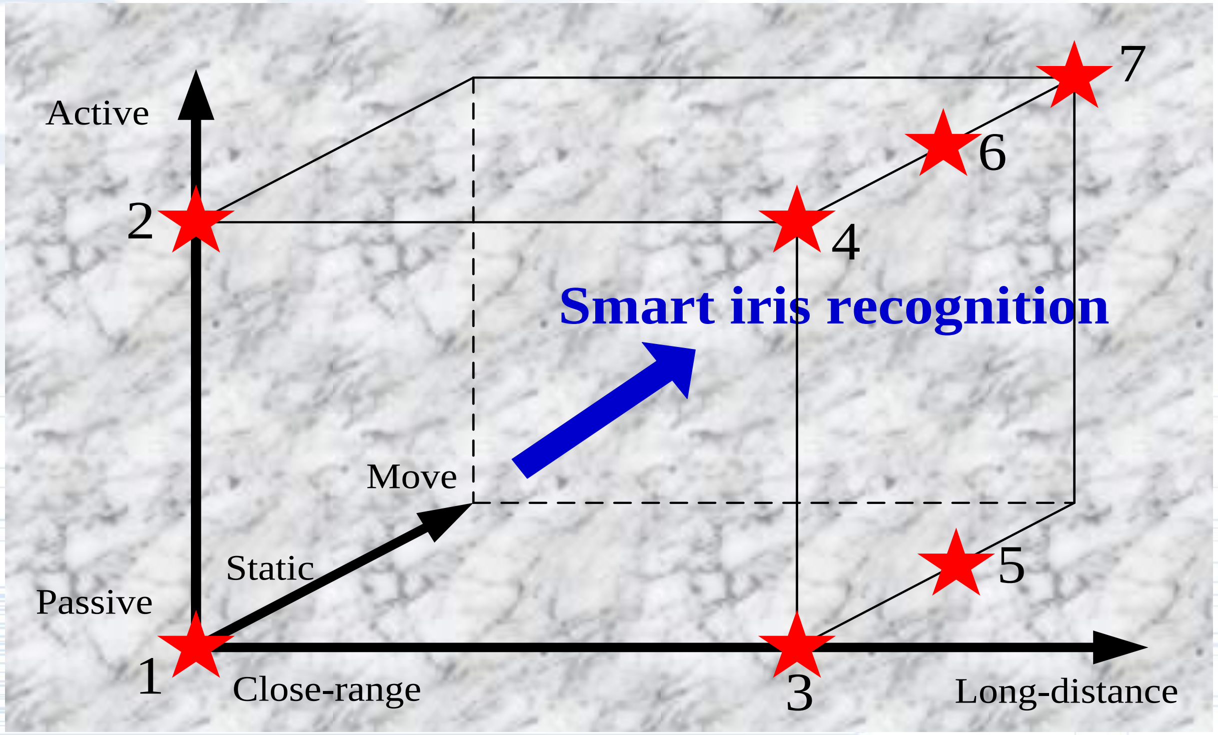


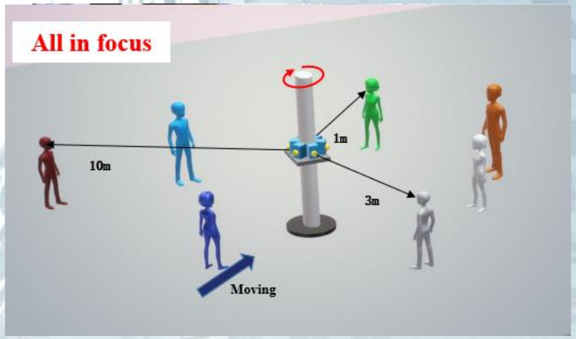
Federated learning
inspired multi-client cooperation

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**

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 user-friendly and robust iris recognition solutions.**

Small Iris, Big Topic, Great Future!

Thank You!