

Signature Biometrics

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1

Funding Acknowledgements

Public

Private

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2

Index

- Introduction
- System Model: Pre-processing, Features, Similarity
- Performance Evaluation: Databases and Benchmarks
- Signature Aging and Template Update
- A Note on Tech Transfers to Industry
- Mobile Signature: Graphical Passwords and Swipe Biometrics
- Recent Advances: Signature Generation and Template Protection
- The Future of Behavioral Biometrics

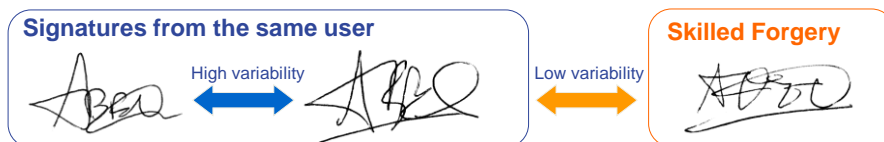
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3

Introduction

- Signature is one of the most **socially accepted** biometric traits, it has been used for centuries to validate legal and commercial documents and transactions
- Automatic signature recognition has some general **challenges**:
 - Large intra-user variability (behavioral biometric, inter-session)
→ Difficult to model, large amount of training data (usually scarce)
 - Small inter-user variability (in case of forgeries)
→ The skill level of actual forgeries is unpredictable



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4

Introduction

- **High deployment** of multiple electronic devices
- Signatures can be **easily captured** by means of multiple devices
- **High deployment in banking and commercial sectors**



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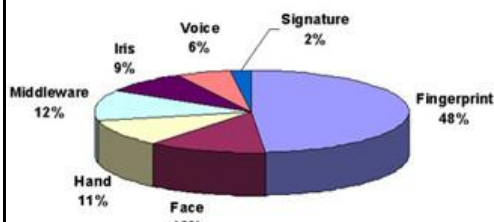


5

Biometric Market by Modality

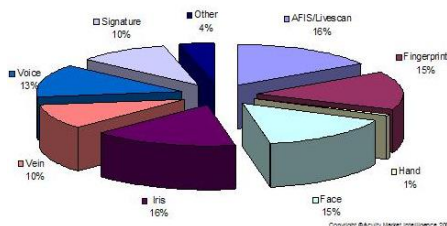
2004 Comparative Market Share by Technology

(not including AFIS revenue)



Copyright (c) 2004 International Biometric Group

Global Market by Technology 2015



Copyright ©Acuity Market Intelligence 2017

- Decreasing (in *Relative Importance*): **Fingerprint**, from 48% to 15% (31% w AFIS)
- Growing: **Iris** from 9% to 16% and **Face** from 12% to 15%
- Huge grow: **Speech** from 6% to 13% and **Signature**, from 2% to 10%

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6

Behavioral Biometrics

- Human activity patterns are clearly established from childhood
- As patterns, they are stable and reproducible, though subject to variability
- Neuromotor coordination of gestures and movements
- Continuous identity monitoring possible
- User is an active part of the play
- Multilevel strategy: from dynamic trajectories to expressions, context, habits, stylometry, experiences
- Not fixed patterns but changing and adapting ones

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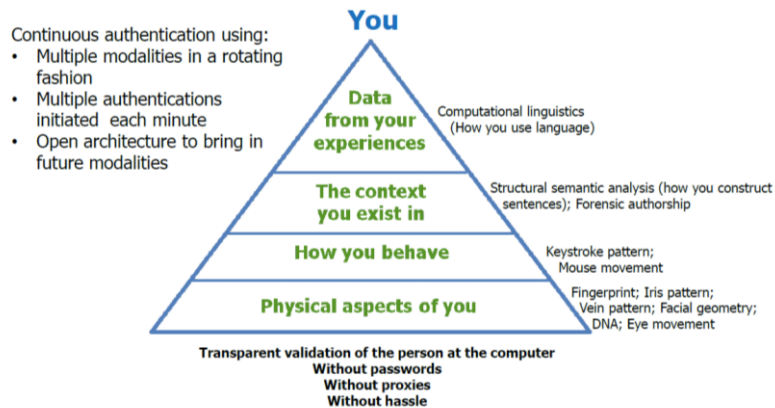
7

Active Authentication by DARPA



Solution: **Active Authentication**

An open solution that provides **meaningful** and **continual** authentication to DoD's computer systems leveraging that which makes up **you**



12/8/2011

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10

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8

Signature as Behavioral Pattern

- Human interaction permits transparent authentication
- Make use of existing input channels, no added specific sensors:
 - Handwriting (tablets and pads)
 - Mouse dynamics
- Other sources of variability (sensor, session) included into behavior pattern modelling / compensation
- Fully revocable patterns
- Incorporates soft biometrics (gender, handedness, language, ...)
- Easy of use, high user acceptance

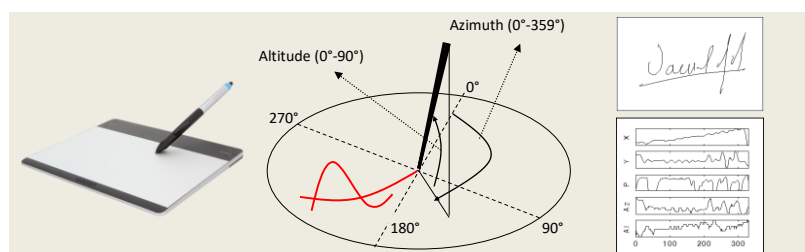
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9

Signature Recognition

On-line / Dynamic



Off-line / Static

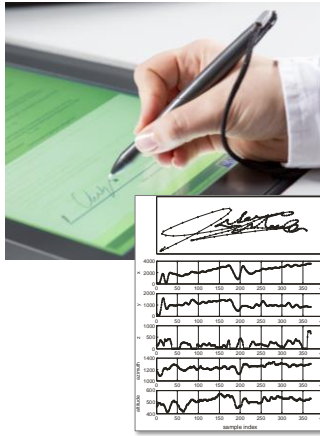


J. Fierrez, J. Ortega-Garcia, et al., "HMM-based on-line signature verification: feature extraction and signature modeling", *Pattern Recognition Letters*, Vol. 28, n. 16, Dec. 2007.

J. Fierrez, and J. Ortega-Garcia, "On-Line Signature Verification", Chapter 10 in *Handbook of Biometrics*, A.K. Jain, A. Ross and P. Flynn (eds.), Springer, pp. 189-209, 2008.

10

On-line Signature Verification: Overview



Dynamic
signature
matching

Feature-based (Global Features)

Distance-based classifiers

- Mahalanobis
- Euclidean [Nelson et al., 1994]

Statistical/other classifiers

- Gaussian Mixture Models (GMM)
- Parzen Windows

Function-based (Local Features)

Time-Sequence matching techniques

- Hidden Markov Models (HMM) [Dolfing et al., 1998]
- Gaussian Mixture Models (GMM) [Richiardi et al., 2005]
- Dynamic Time Warping (DTW) [Sato and Kogure, 1982]

J. Fierrez and J. Ortega-Garcia, "On-line signature verification", A.K. Jain et al. (Eds), *Handbook of Biometrics*, 2008.

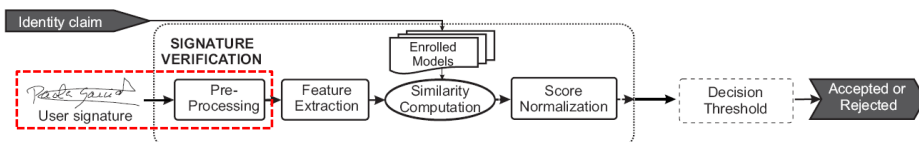
M. Martinez-Diaz and J. Fierrez, "Signature Databases and Evaluation", Stan Z. Li and Anil K. Jain (Eds.), *Encyclopedia of Biometrics*, Springer, pp. 1367-1375, 2015.

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11

On-line Signature Verification: System Model



1. Data Acquisition & Pre-Processing

2. Feature Extraction

3. Similarity Computation (Matching)

J. Fierrez and J. Ortega-Garcia, "On-line signature verification", A.K. Jain et al. (Eds), *Handbook of Biometrics*, 2008.

12

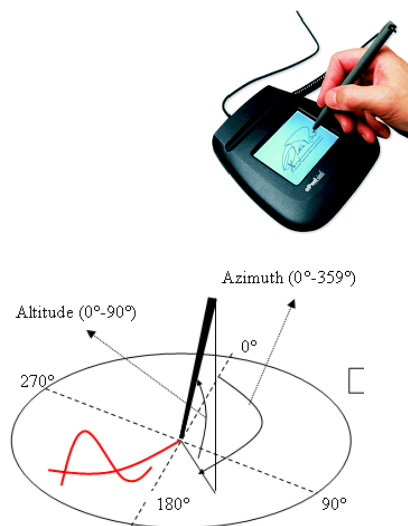
Signature Acquisition: Input Data

Time resolution: 100-200 samples/sec

Space resolution: 1000 pixels/inch resolution

Measured:

- x,y coordinates of the signature trajectory
 - on pen down
- time stamp at each sample point
- pressure at each point
- pen inclination angles at each point
 - altitude (0-90)
 - azimuth (0-359)
- ...



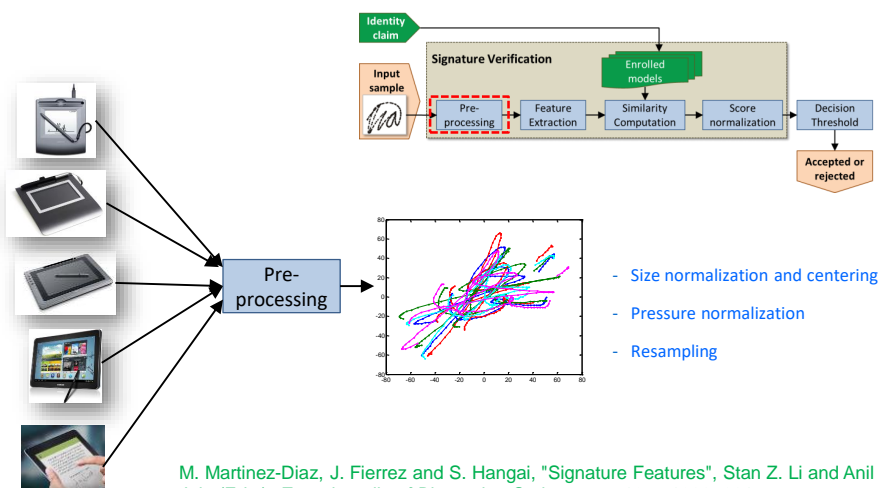
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13

Signature Pre-Processing

Reduce sensor interoperability issues due to diverse devices and writing tools (stylus/finger)

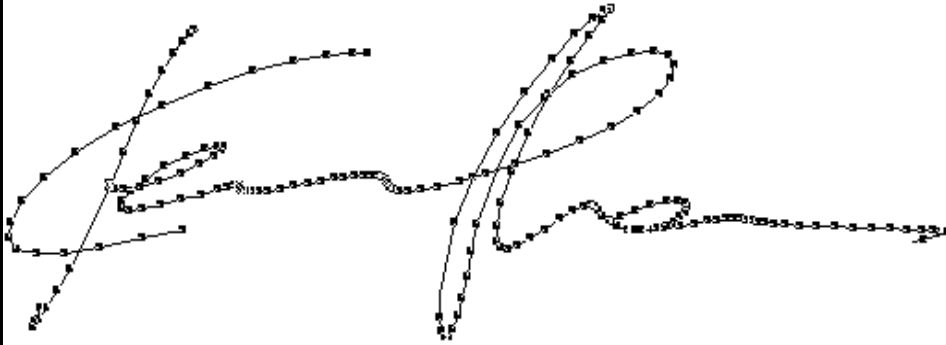


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14

Pre-Processing: Re-Sampling



M. Martinez-Diaz, J. Fierrez and S. Hangai, "Signature Features", Stan Z. Li and Anil K. Jain (Eds.), *Encyclopedia of Biometrics*, Springer, pp. 1375-1382, 2015.

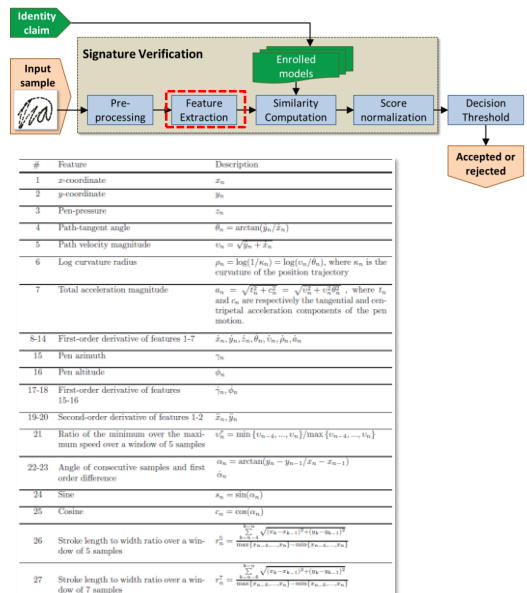
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15

Feature Extraction

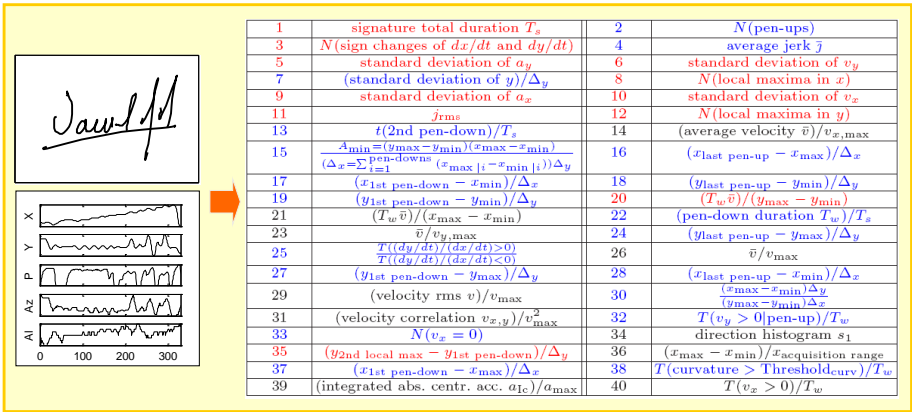
#	Feature Description	#	Feature Description
1	signature total duration T_s	2	(pen-down duration T_{pd})/ T_s
3	($\text{lat } t_{(v_{\max})}$)/ T_s	4	$T(v_x > 0)/T_s$
5	$T(v_x < 0)/T_s$	6	$T(v_y > 0)/T_s$
7	$T(v_x < 0 \text{ pen-up})/T_s$	8	$T(v_x > 0 \text{ pen-up})/T_s$
9	$T(v_x < 0 \text{ pen-down})/T_s$	10	$T(v_x > 0 \text{ pen-down})/T_s$
11	$T(v_y < 0 \text{ pen-up})/T_s$	12	$T(v_y > 0 \text{ pen-up})/T_s$
13	$T(2\text{nd pen-up})/T_s$	14	$T(2\text{nd pen-down})/T_s$
15	$T(\text{3rd pen-down})/T_s$	16	($\text{lat } t_{(v_{y,\max})}$)/ T_s
17	($\text{lat } t_{(v_{x,\max})}$)/ T_s	18	($\text{lat } t_{(v_{y,\max})}$)/ T_s
19	($\text{lat } t_{(v_{x,\max})}$)/ T_s	20	($\text{lat } t_{(v_{y,\max})}$)/ T_s
21	$T(\text{curvature} > \text{threshold}_{\text{cur}})/T_s$	22	($\text{lat } t_{(v_{x,\max})}$)/ T_s
23	($2\text{nd } t_{(v_{x,\max})}$)/ T_s	24	($3\text{rd } t_{(v_{x,\max})}$)/ T_s
25	($2\text{nd } t_{(v_{y,\max})}$)/ T_s	26	($3\text{rd } t_{(v_{y,\max})}$)/ T_s
27	(average velocity \bar{v})/ v_{\max}	28	$N(v_x = 0)$
29	$N(v_y = 0)$	30	$N(v_{\max})$
31	$N(v_{\max})$	32	(velocity max v)/ v_{\max}
33	(centripetal acceleration run a_c)/ a_{\max}	34	(tangential acceleration run a_t)/ a_{\max}
35	(acceleration run a)/ a_{\max}	36	(tangential acc. center acc. a_{tc})/ a_{\max}
37	(velocity correlation v_{xy})/ v_{\max}^2	38	standard deviation of v_x
39	standard deviation of v_y	40	standard deviation of a_x
41	standard deviation of a_y	42	entropy [bits]
43	\bar{x}	44	\bar{y}
45	\bar{z}_{\max}	46	\bar{z}_{\min}
47	\bar{z}_{\max}	48	\bar{z}_{\min}
49	$t_{(x,\max)}/T_s$	50	$t_{(x,\min)}/T_s$
51	$t_{(y,\max)}/T_s$	52	$t_{(y,\min)}/T_s$
53	$N(\text{sign changes of } dx/dt \text{ and } dy/dt)$	54	$N(\text{sign changes of } dx/dt \text{ and } dy/dt)$
55	$\theta(\text{initial direction})$	56	$\theta(\text{initial direction})$
57	$\theta(\text{1st pen-down to 1st pen-up})$	58	$\theta(\text{1st pen-down to 1st pen-up})$
59	$\theta(\text{2nd pen-down to 2nd pen-up})$	60	$\theta(\text{2nd pen-down to 2nd pen-up})$
61	$\theta(\text{1st pen-down to last pen-up})$	62	$\theta(\text{1st pen-down to last pen-up})$
63	direction histogram a_1	64	direction histogram a_2
65	direction histogram a_3	66	direction histogram a_4
67	direction histogram a_5	68	direction histogram a_6
69	direction histogram a_7	70	direction change histogram c_1
71	direction change histogram c_2	72	direction change histogram c_3
73	(max distance between points)/ A_{\max}	74	(max distance between points)/ A_{\max}
75	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy	76	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy
77	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx	78	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx
79	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy	80	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy
81	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx	82	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx
83	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy	84	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy
85	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx	86	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx
87	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy	88	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy
89	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx	90	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx
91	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy	92	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy
93	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx	94	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx
95	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy	96	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy
97	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx	98	($\text{1st pen-down} - \text{1st pen-up}$)/ Δx
99	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy	100	($\text{1st pen-down} - \text{1st pen-up}$)/ Δy



M. Martinez-Diaz, J. Fierrez, et al., "Mobile Signature Verification: Feature Robustness and Performance Comparison", *IET Biometrics*, Dec 2014.

16

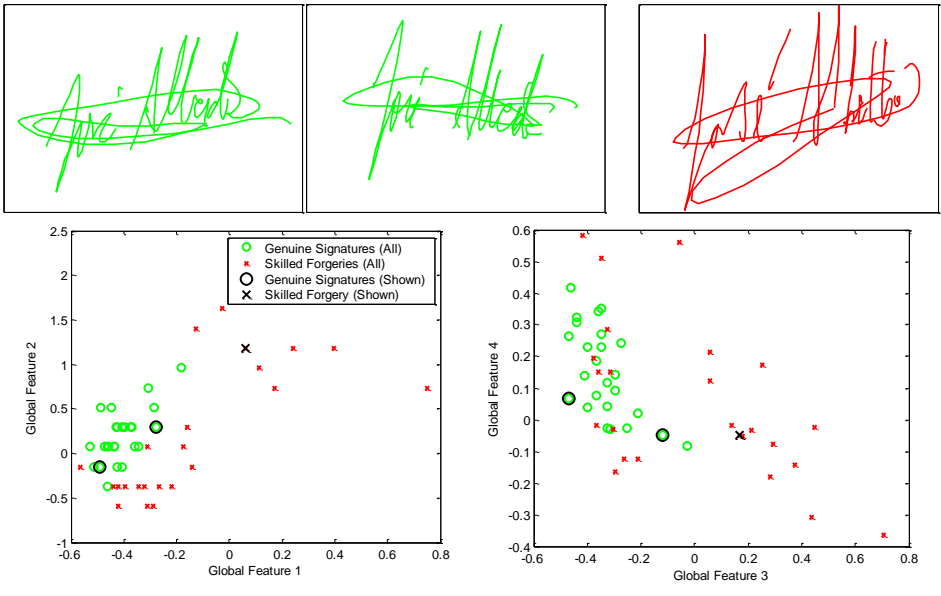
Feature Extraction: Global Features



M. Martinez-Diaz, J. Fierrez, et al., "Mobile Signature Verification: Feature Robustness and Performance Comparison", *IET Biometrics*, Dec 2014.

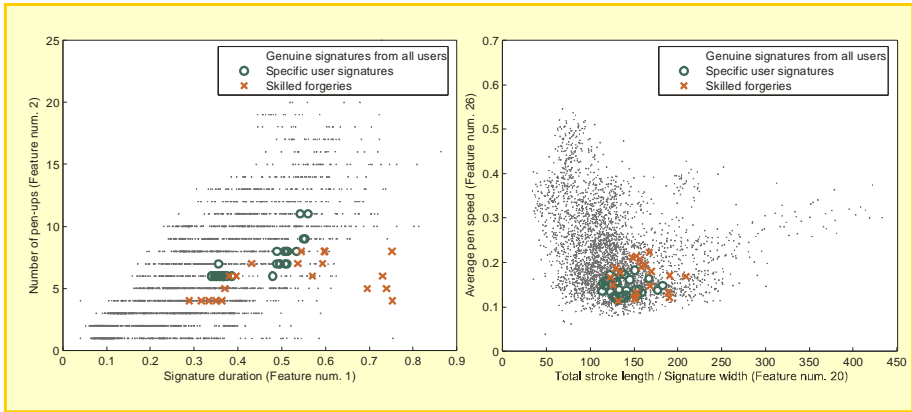
17

Feature Extraction: Global Features Example



18

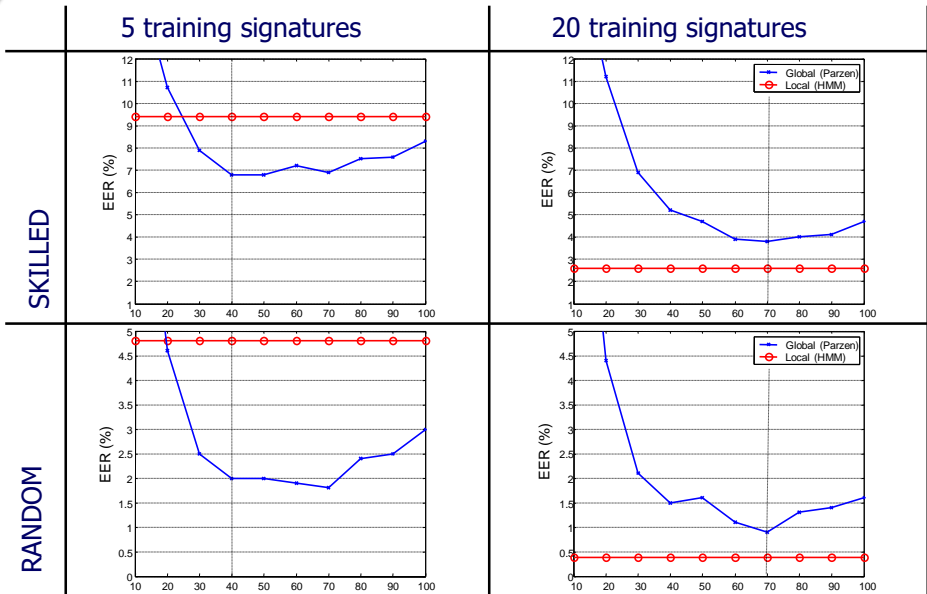
Feature Extraction: Global Features Example



M. Martinez-Diaz, J. Fierrez, et al., "Mobile Signature Verification: Feature Robustness and Performance Comparison", *IET Biometrics*, Dec 2014.

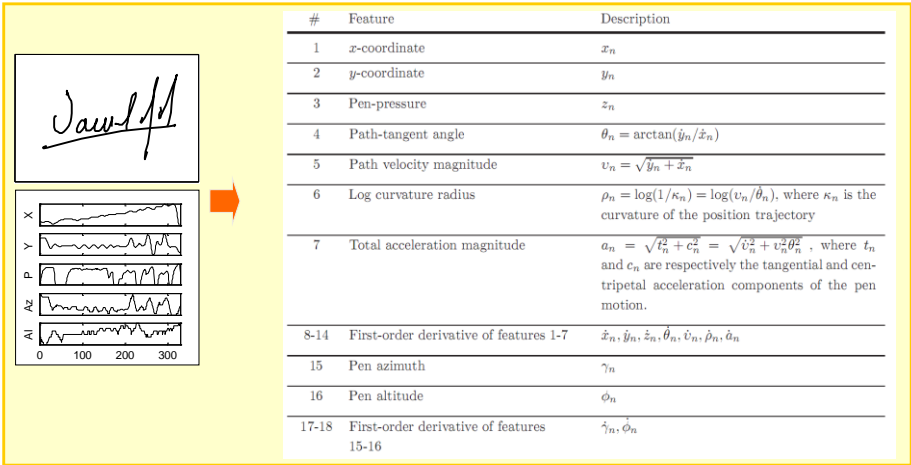
19

Global Features: Performance (on MCYT DB)



20

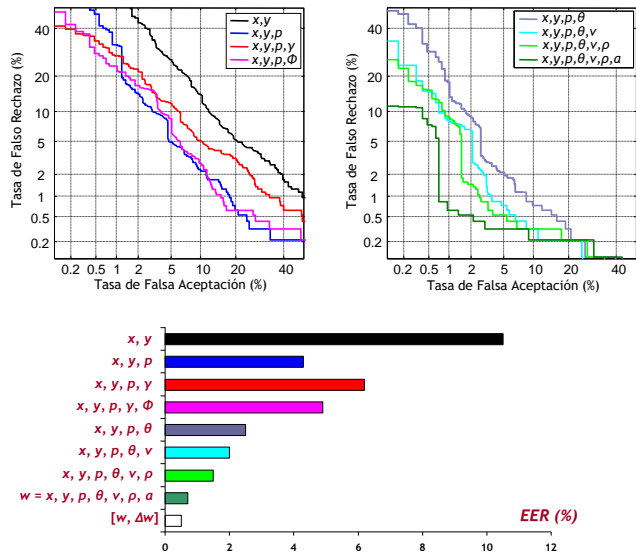
Feature Extraction: Time Sequences



J. Fierrez, J. Ortega-Garcia, et al., "HMM-based on-line signature verification: feature extraction and signature modeling", *Pattern Recognition Letters*, Vol. 28, n. 16, Dec. 2007.

21

Feature Extraction: Time Sequences



J. Fierrez, J. Ortega-Garcia, et al., "HMM-based on-line signature verification: feature extraction and signature modeling", *Pattern Recognition Letters*, Vol. 28, n. 16, Dec. 2007.

22

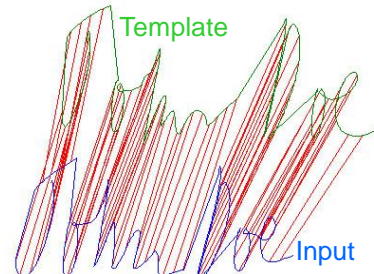
Dynamic Time Warping

$$D(i, j) = \min \begin{cases} D(i-1, j-1) + d_E(i, j) \\ D(i-1, j) + d_E(i, j) * c \\ D(i, j-1) + d_E(i, j) * c \\ d_E(i, j) < thresh \rightarrow 0 \end{cases}$$

D serves to define the optimal alignment between point i in the input signature and point j in the template, which is computed via **dynamic programming**.

A constant factor c multiplied by the Euclidean distance between the two feature vectors is used instead of constant penalties.

No penalty if the Euclidean distance is small.



Correspondences found by the DTW algorithm

M. Martinez-Diaz, J. Fierrez and S. Hangai, "Signature Matching", Stan Z. Li and Anil K. Jain (Eds.), *Encyclopedia of Biometrics*, Springer, pp. 1375-1382, 2015.

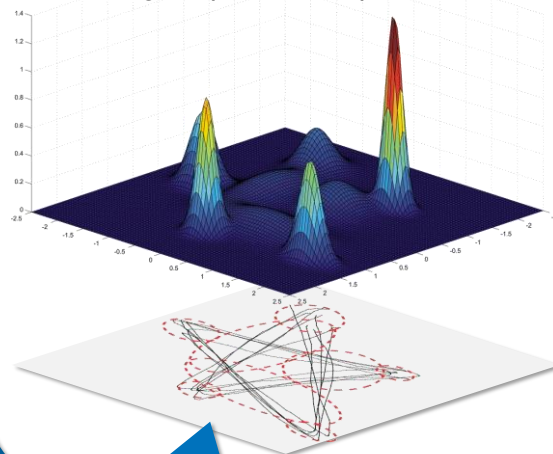
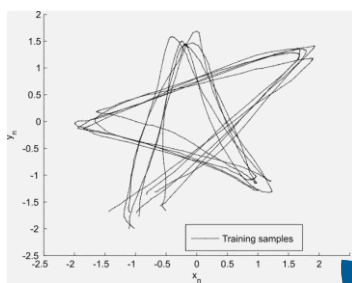
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25

Stochastic Approach: Gaussian Mixture Models

- Probability of occurrence modeled through a mixture of Gaussians
- Model constructed with several training samples to incorporate sample variability
- Compact representation



J. Fierrez, J. Ortega-Garcia, et al., "HMM-based on-line signature verification: feature extraction and signature modeling", *Pattern Recognition Letters*, Dec 2007.

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26

Performance Evaluation: Signature Databases

- Databases allow **systematic evaluation** of algorithms
- **Large** publicly available databases are **scarce**, mainly due to
 - **Legal and privacy** issues
 - **Huge resources** needed to capture and process the data
- **MCYT database** has been the most widely used dataset since 2003, reaching performances on 330 subjects below 1% ERR
- **Other existing databases** include SVC, Biomet, Myldea, Susig
- Recently, new databases containing **additional features** have been captured (e.g, BioSecure Multimodal Database, e-BioSign)

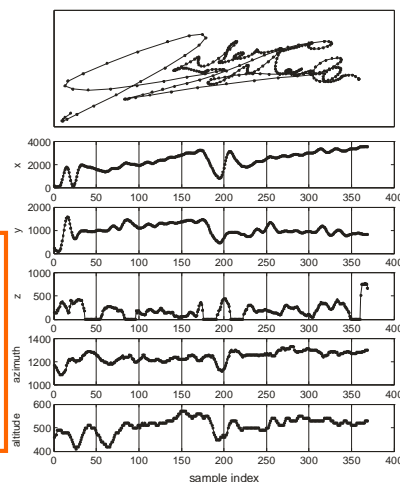
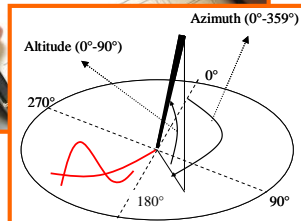
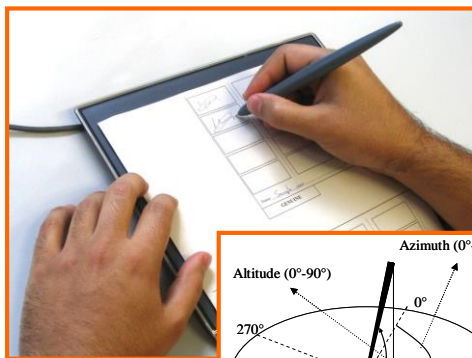
J. Ortega-Garcia, J. Fierrez *et al.*, "MCYT Baseline Corpus: A Multimodal Biometric Database", IEE Proceedings - Vision, Image and Signal Processing, Vol. 150, No. 6, pp. 395-401, December 2003.

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27

Traditional Acquisition Scenario (2000-2015)



M. Martinez-Diaz and J. Fierrez, "Signature Databases and Evaluation", Stan Z. Li and Anil K. Jain (Eds.), *Encyclopedia of Biometrics*, Springer, pp. 1367-1375, 2015.

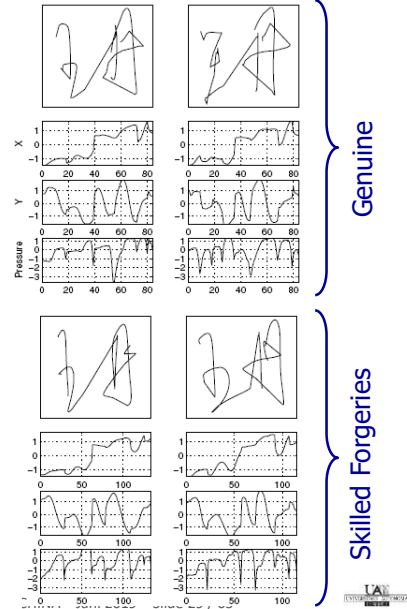
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28

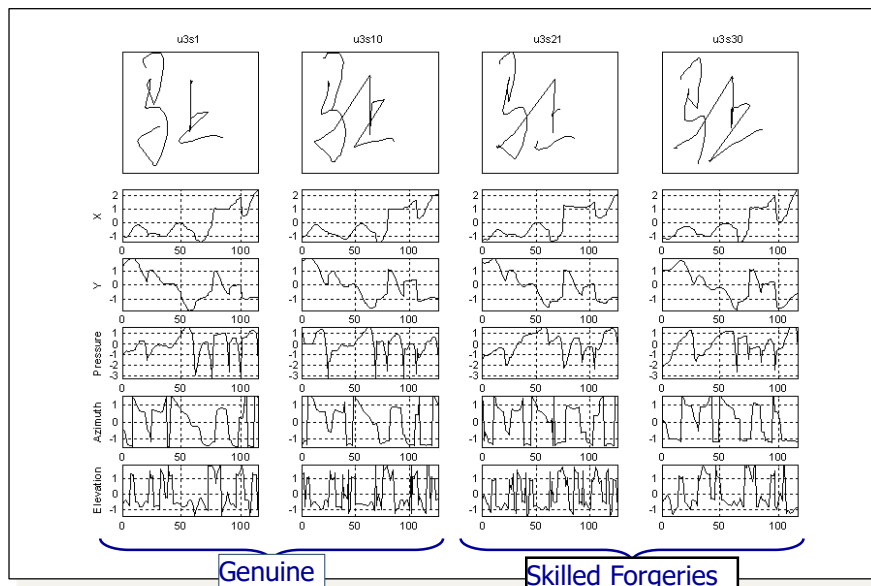
Benchmarks: SVC 2004

- Challenging data:
 - WACOM Intuos pen tablet with inkless pen (i.e., without visual feedback).
 - Invented signatures different to the ones used in daily life.
 - English and Chinese signatures.
 - Impostors know the dynamics of the signatures being forged.
- Acquisition protocol:
 - 40 subjects.
 - 20 genuine signatures (2 sessions) + 20 skilled forgeries (from five impostors)
- Publicly available:
<http://www.cs.ust.hk/svc2004/>



29

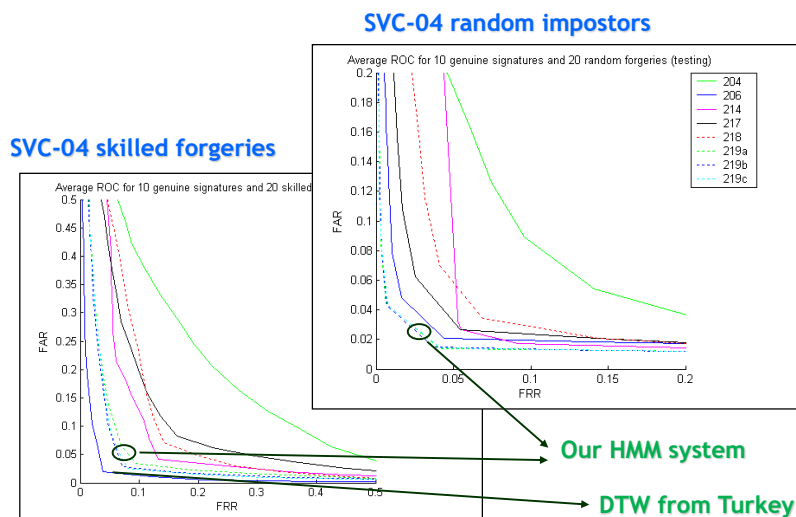
Benchmarks: SVC 2004



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30

Benchmarks: SVC 2004



<http://www.cs.ust.hk/svc2004/>

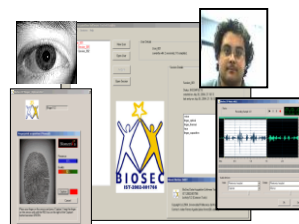
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31

Resources: Multimodal Databases w Signature

- **MCYT Database** (Spanish Project 2000-2003)
 - Fingerprint (with human-labeled quality) and on-line **Signature of 330 donors**
- **BiosecurID Database** (Spanish Project 2003-2006)
 - 8 Modalities: speech, iris, face, **Signature** and handwriting (on-line and off-line), fingerprints, hand and keystroking of **400 donors** in 4 acquisition sessions
- **Biosecure Database** (EU Project 2004-2007)
 - 3 Datasets: Web scenario, Office scenario, Mobile scenario
 - **667 donors**



See: <https://atvs.ii.uam.es/atvs/databases.jsp>

J. Ortega-Garcia, J. Fierrez-Aguilar, et al., "MCYT baseline corpus: A bimodal biometric database", *IEEE Proceedings Vision, Image and Signal Processing*, December 2003.

J. Fierrez, J. Galbally, et al., "BiosecurID: A Multimodal Biometric Database", *Pattern Analysis and Applications*, Vol. 13, n. 2, pp. 235-246, May 2010.

J. Ortega, J. Fierrez, et al., "The BioSecure Multimodal Database", *IEEE Trans. PAMI*, June 2010.

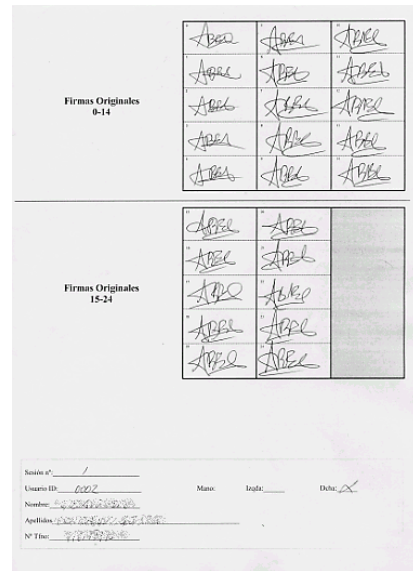
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32

Acquisition Example: MCYT Signature

- Acquisition procedure:
 - WACOM Intuos pen tablet.
 - Ink pen over paper → both on-line and off-line corpus.
 - Restricted size grid guidelines.
- Acquisition protocol:
 - 330 subjects.
 - 25 genuine signatures (five sessions) + 25 skilled forgeries (from five impostors)



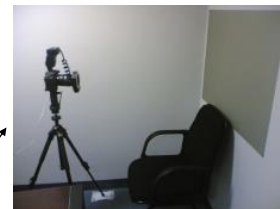
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33

Acquisition Example: Biosecure Multimodal DB

PHILIPS SPC 900NC + PLANTRONICS Voyager 510		
LG IrisAccess EOU3000		
BIOMETRIKA FX2000		
YUBEE (Atmel FingerChip)		
WACOM Intuos A6 + Inking Pen		
CANON EOS 30D + Ring Flash		



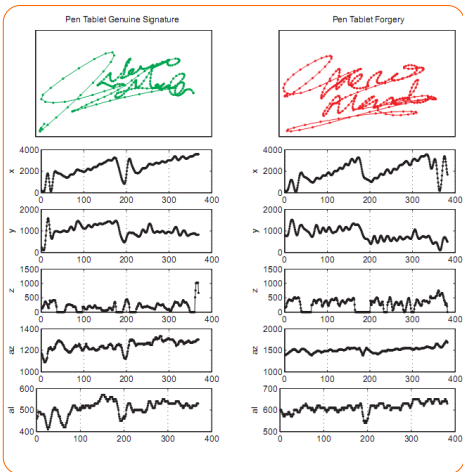
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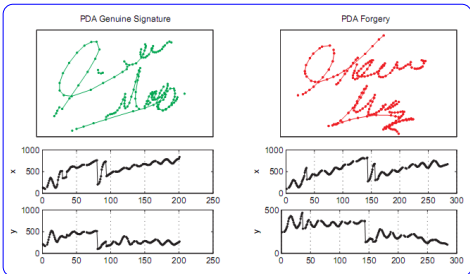
34

Examples from Biosecure MDB

Tablet



Mobile

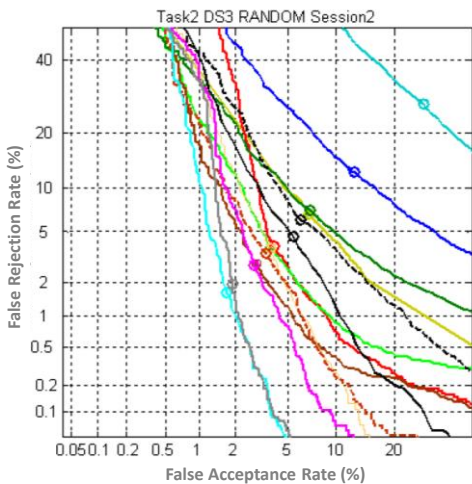


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35

Benchmarks: BSEC 2009



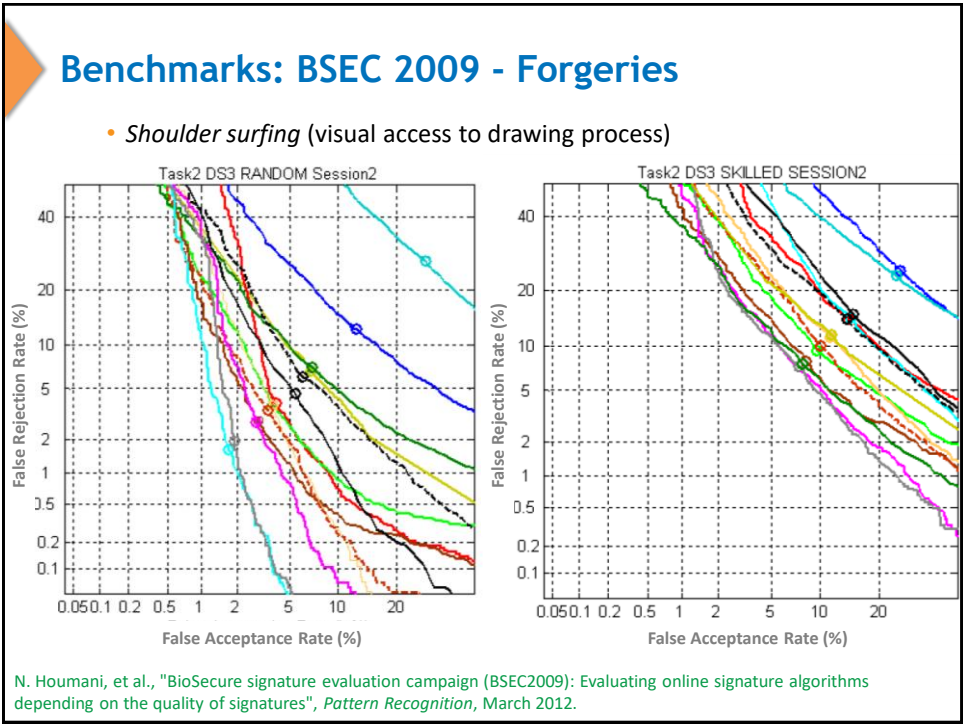
- DTW, HMM and Global Systems
- Score normalization
- Fusion of systems

N. Houmani, et al., "BioSecure signature evaluation campaign (BSEC2009): Evaluating online signature algorithms depending on the quality of signatures", *Pattern Recognition*, March 2012.

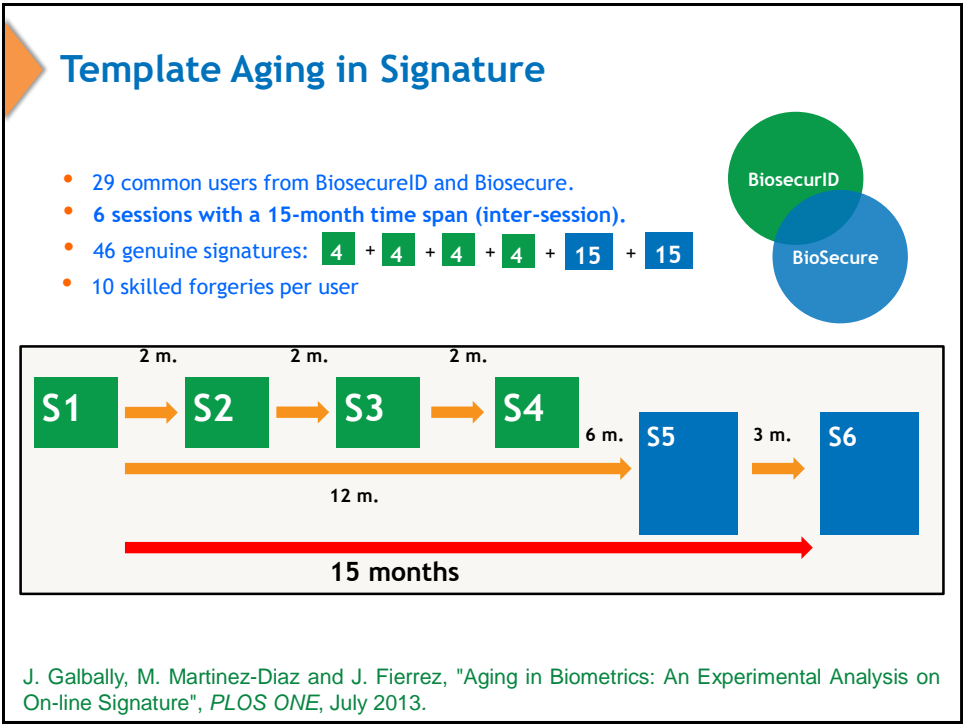
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36





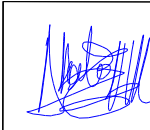


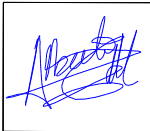

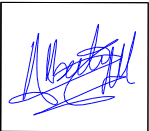


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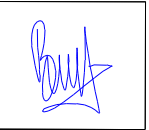

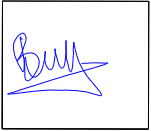

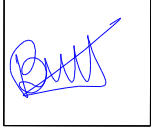


38

Examples of the multi-session DB


BID 1	BID 2	BID 3	BID 4
			
Bure 1-1	Bure 1-2	Bure 1-3	
			
Bure 2-1	Bure 2-2	Bure 2-3	
			

39

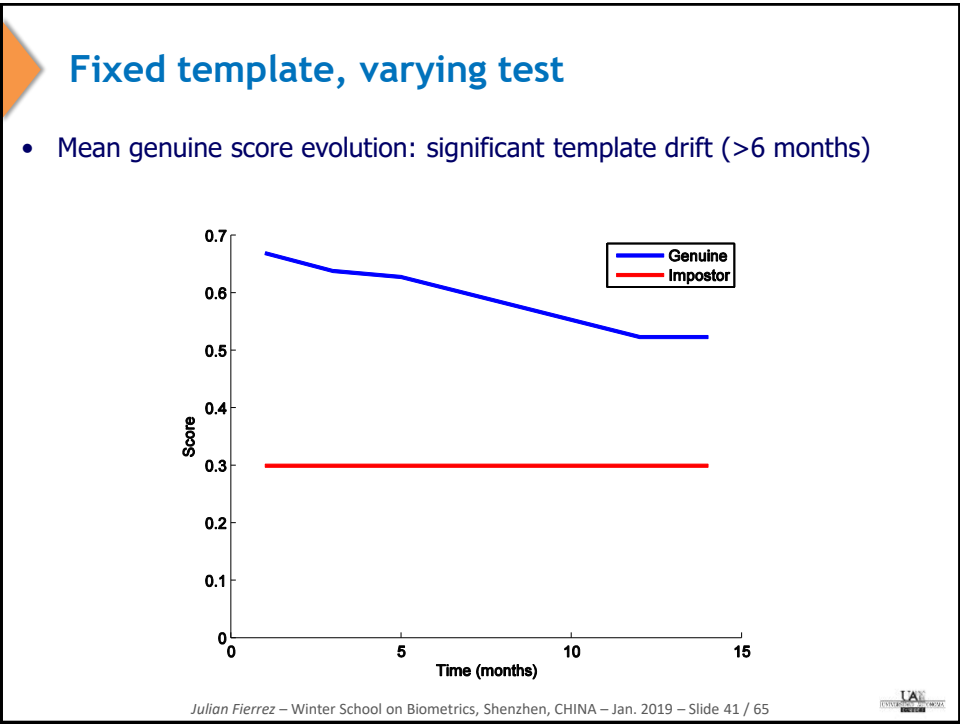
Examples of the multi-session DB

BID 1	BID 2	BID 3	BID 4
			
Bure 1-1	Bure 1-2	Bure 1-3	
			
Bure 2-1	Bure 2-2	Bure 2-3	
			

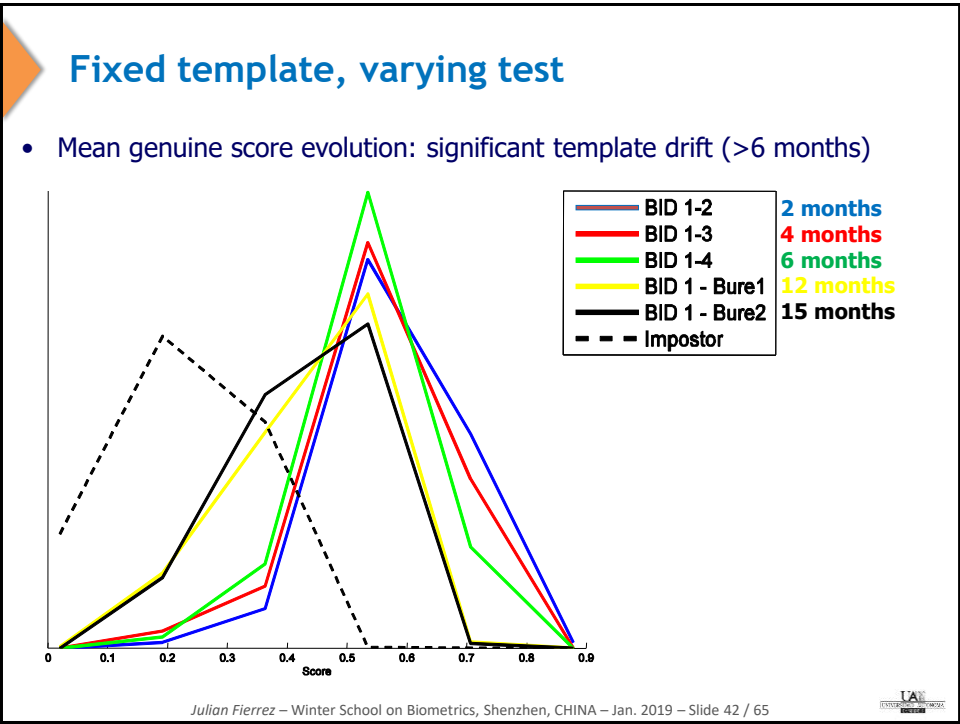
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40

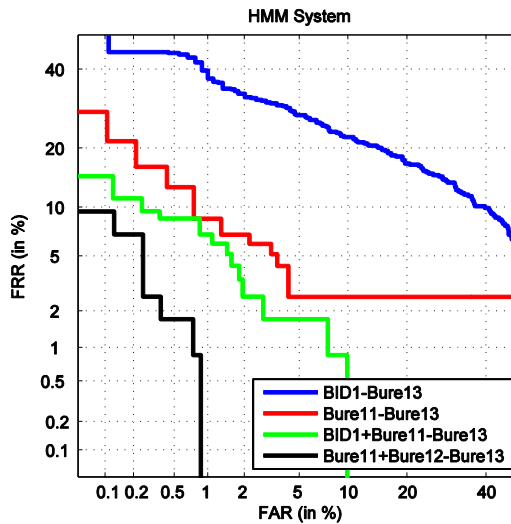


41



42

Template Update: Fixed test, varying enrollment



Reference: 12 months (4 sign.)

Complete update (4 sign.)

Mixed update (4 + 4 sign.)

Complete update (8 sign.)

Compared to the reference scenario (12 months train-test):

- Significant improvement by forgetting and retraining using a small set of new training data.
- This can be further improved by not forgetting but adapting using the new data.
- Enough new train data available → better than using old data.

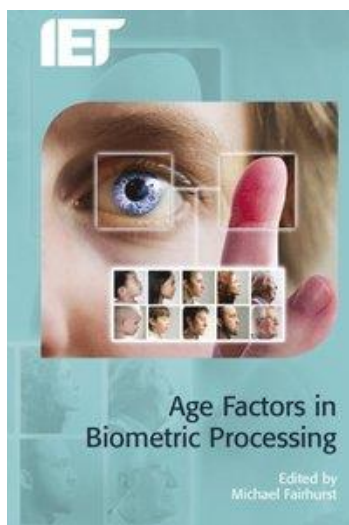
DATA-DEPENDENT PROBLEM,
STRONGLY DEPENDENT ON THE
AMOUNT OF TRAINING DATA

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43

More on Biometric Aging and Template Update



J. Galbally, M. Martinez-Diaz and J. Fierrez, "Aging in Biometrics: An Experimental Analysis on On-line Signature", *PLOS ONE*, July 2013.

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44

Performance in 2015 → BIOTRACE100

- Accuracy (Signature Long-Term - SLT Database):

	4 training signatures	16 signatures	31 signatures	41 signatures
Random Forg.	97.2 %	99.3 %	99.9 %	99.9 %
Skilled Forg.	88.3 %	93.1 %	95.9 %	99.3 %

- State of the art performance
- Template and system configuration update strategies in order to minimize the aging effect

R. Tolosana, R. Vera-Rodriguez, J. Ortega-Garcia and J. Fierrez, "Preprocessing and Feature Selection for Improved Sensor Interoperability in Online Biometric Signature Verification", *IEEE Access*, Vol. 3, pp. 478 - 489, May 2015.

45

Banking Industry - Tech Transfer to **cecabank**
SERVICIOS FINANCIEROS

- Stylus and finger-drawn signature recognition
- Off-line fraud detection and on-line verification
- Semi-automatic tools to aid experts in signature comparison (lawsuits)



Dynamic signature acquisition and management solution already in operation
(> 46k sensors, > 500M operations/year)

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46

e-BioSign DB (2016-2017)



WACOM STU-500

WACOM STU-530

WACOM DTU-1031

SAMSUNG ATIV 7 (WIN8)

SAMSUNG GALAXY NOTE 10.1 (ANDROID)

- 70 users, 2 capturing sessions. 5 devices (4 Wacom, 4 Samsung)
- 8 genuine signatures and 6 skilled forgeries per user and device
- Stylus and finger as writing tools (Samsung)

R. Tolosana, R. Vera-Rodriguez, J. Fierrez, A. Morales, J. Ortega-Garcia, "Benchmarking Desktop and Mobile Handwriting across COTS Devices: the e-BioSign Biometric Database" *PLOS ONE*, 2017.

47

2017 Performance on e-BioSign (Modern Devices)

	W1	W2	W3	W4	W5	EER _{skilled} EER _{random}
W1	10.7 0.7	7.9 0.8	15.7 5.0	10.7 0.7	10.7 2.1	
W2	11.4 1.1	10.0 0.7	16.4 5.7	14.3 0.7	11.4 1.6	
W3	9.3 0.3	8.6 0.7	13.6 2.1	11.2 0.0	11.4 1.4	
W4	10.0 0.7	9.3 0.9	17.1 5.0	10.7 0.7	11.4 1.4	
W5	12.7 1.4	10.0 1.1	16.9 5.0	12.1 0.7	11.2 1.4	


Pen Stylus Input

	W4	W5
W4	19.3 0.7	23.5 0.2
W5	24.2 0.7	22.9 0.3

Finger Input

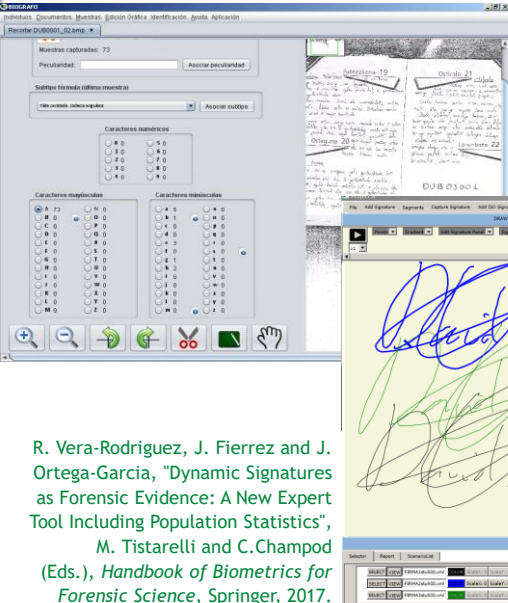
R. Tolosana, R. Vera-Rodriguez, J. Fierrez, A. Morales, J. Ortega-Garcia, "Benchmarking Desktop and Mobile Handwriting across COTS Devices: the e-BioSign Biometric Database", *PLOS ONE*, 2017.

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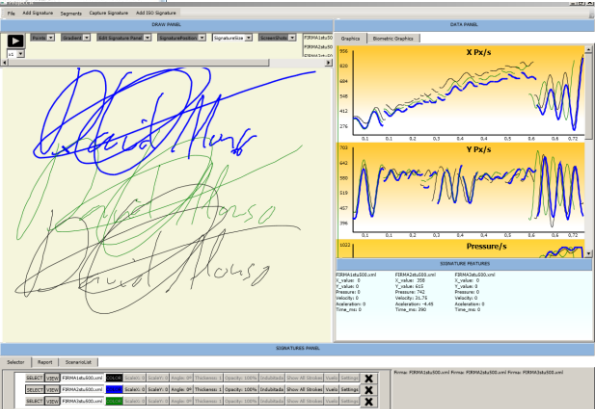
48

Handwriting/Sign Tech Transfers to Forensic Labs



J. Galbally, S. Gonzalez-Dominguez, J. Fierrez and J. Ortega-Garcia, "Biografo: An integrated tool for forensic writer identification", in *Proc. Intl. Workshop on Computational Forensics*, Springer LNCS-8915, November 2015.

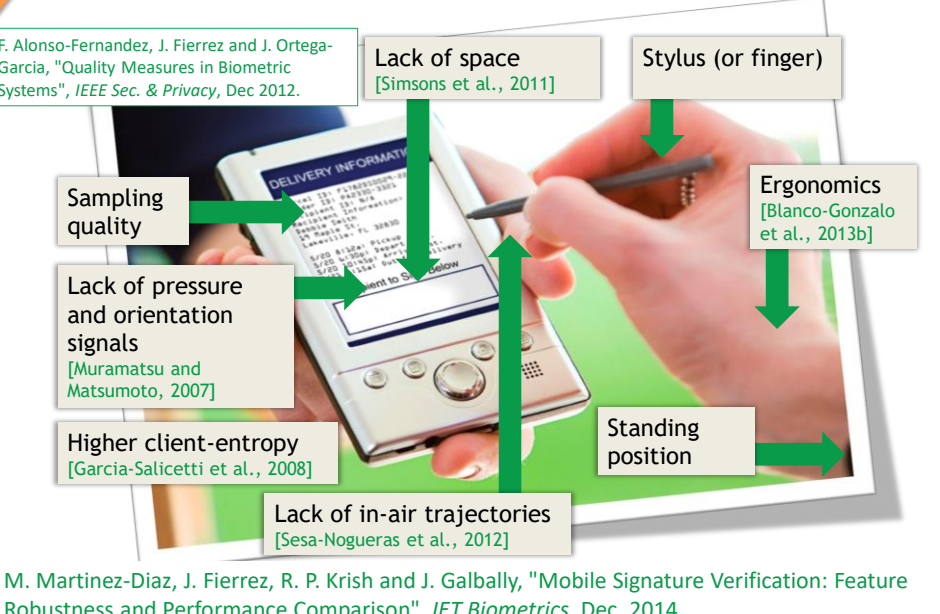
R. Vera-Rodriguez, J. Fierrez and J. Ortega-Garcia, "Dynamic Signatures as Forensic Evidence: A New Expert Tool Including Population Statistics", M. Tistarelli and C.Champod (Eds.), *Handbook of Biometrics for Forensic Science*, Springer, 2017.



49

Signature in Mobile Devices

F. Alonso-Fernandez, J. Fierrez and J. Ortega-Garcia, "Quality Measures in Biometric Systems", *IEEE Sec. & Privacy*, Dec 2012.



Lack of space [Simmons et al., 2011]

Stylus (or finger)

Ergonomics [Blanco-Gonzalo et al., 2013b]

Standing position

Lack of in-air trajectories [Sesa-Nogueras et al., 2012]

Higher client-entropy [Garcia-Salicetti et al., 2008]

Lack of pressure and orientation signals [Muramatsu and Matsumoto, 2007]

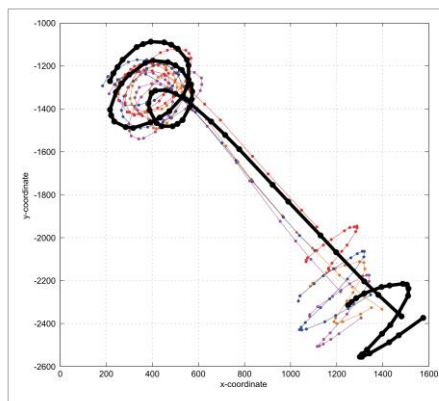
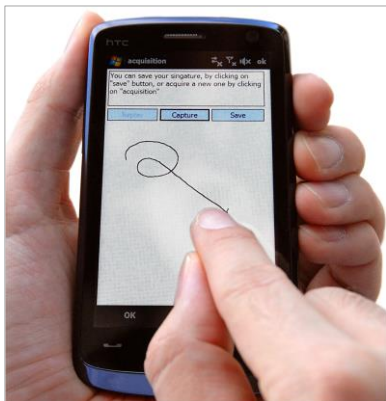
Sampling quality

M. Martinez-Diaz, J. Fierrez, R. P. Krish and J. Galbally, "Mobile Signature Verification: Feature Robustness and Performance Comparison", *IET Biometrics*, Dec. 2014.

50

From Signature to Touch Gestures

- Graphical Password-based User Authentication with Free-form Doodles



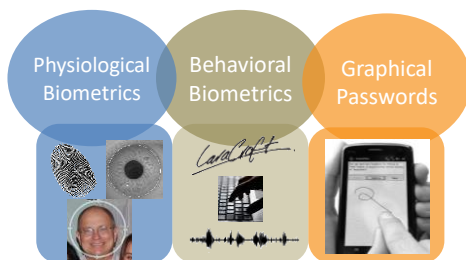
M. Martinez-Diaz, J. Fierrez and J. Galbally, "Graphical Password-based User Authentication with Free-Form Doodles", *IEEE Trans. on Human-Machine Systems*, August 2016.

M. Martinez-Diaz, J. Fierrez, and J. Galbally. "The DooDB graphical password database: Data analysis and benchmark results", *IEEE Access*, September 2013.

51

Graphical Passwords

- Gesture-based authentication on touch-screens
- Slow typing in touchscreens
- Biometric-rich gestures
- Revocability



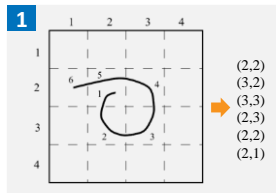
M. Martinez-Diaz, J. Fierrez and J. Galbally, "The DooDB Graphical Password Database: Data Analysis and Benchmark Results", *IEEE Access*, Sept. 2013.

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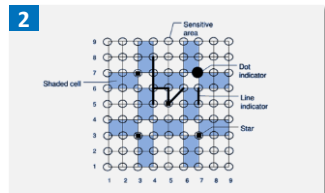


52

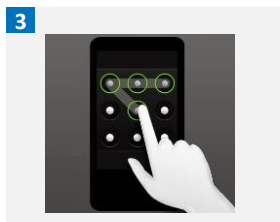
Graphical Passwords: Related Works



Draw a Secret [Jermyn et al., 1999]
US Patent 8024775 B2



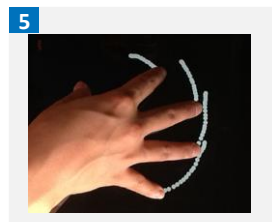
Pass-Go [Tao et al., 2008]



Pattern Lock [Google]
US Patent 20130047252 A1



Picture Gesture Authentication [Microsoft]
US Patent 20130047252 A1



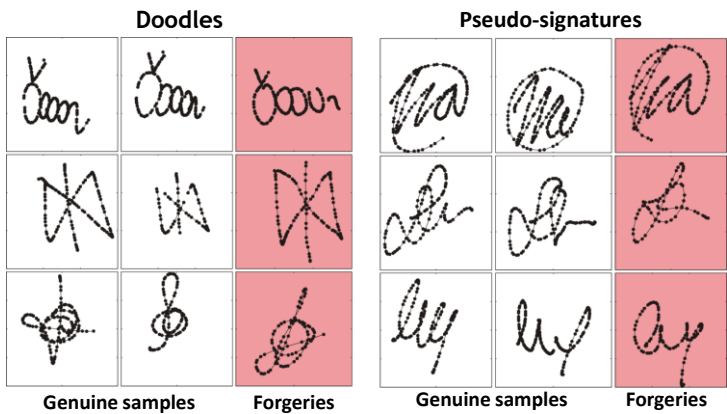
Multi-touch gestures [Sae-Bae et al., 2012]
US Patent 20130219490 A1

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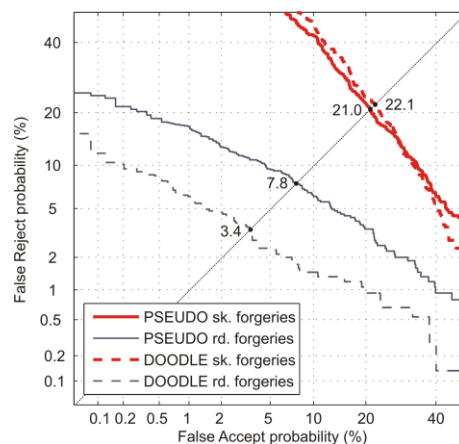
53

Graphical Examples



Some Initial Results

- Verification performance on the validation set
- Just x, y features
- Score fusion of GMM and DTW



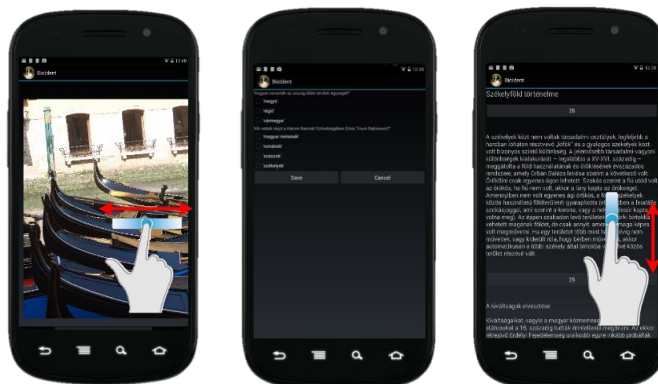
M. Martinez-Diaz, J. Fierrez and J. Galbally, "The DooDB Graphical Password Database: Data Analysis and Benchmark Results", *IEEE Access*, Sept. 2013.

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55

Current Work: Swipe Biometrics

- Continuous user authentication through touch biometrics:
 - Security beyond the entry-point
- Situation:
 - Freely interacting with the touchscreen while reading or viewing images

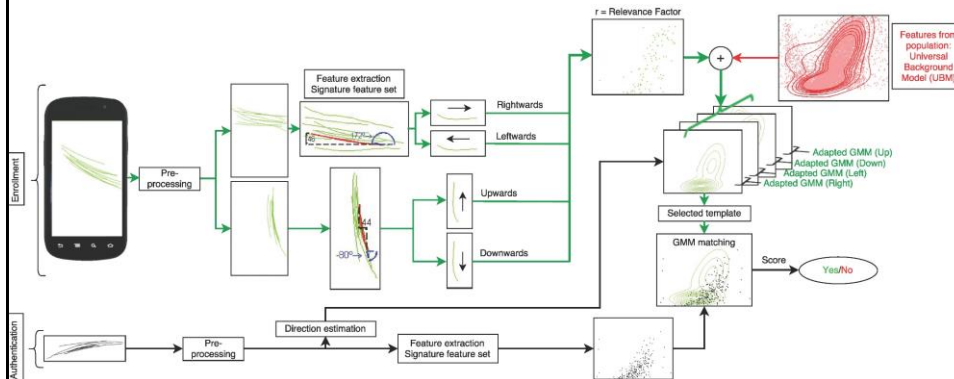


J. Fierrez, A. Pozo, M. Martinez-Diaz, J. Galbally and A. Morales, "Benchmarking Touchscreen Biometrics for Mobile Authentication", *IEEE Trans. on Information Forensics and Security*, November 2018.

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56

Current Work: Swipe Biometrics



J. Fierrez, A. Pozo, M. Martinez-Diaz, J. Galbally and A. Morales, "Benchmarking Touchscreen Biometrics for Mobile Authentication", *IEEE Trans. on Information Forensics and Security*, November 2018.

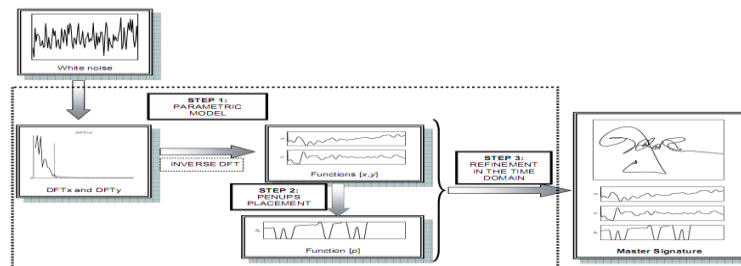
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57

Other Recent Advances: Synthetic Signature Generation

- Novel signature generation schemes using **data-driven spectral features**, or **human neuromotor properties**, which generate realistic yet random full X, Y, and Pressure signature signals.
- Useful for improving the training with limited data.



J. Galbally, J. Fierrez, J. Ortega-Garcia and R. Plamondon, "Synthetic on-line signature generation. Part II: Experimental validation", *Pattern Recognition*, Vol. 45, pp. 2622-2632, July 2012.

J. Galbally, et al., "On-Line Signature Recognition Through the Combination of Real Dynamic Data and Synthetically Generated Static Data", *Pattern Recognition*, Sept. 2015.

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58

Other Recent Advances: Template Protection

- Biometric data can be compromised if raw signals are stored
- **Template protection schemes** needed to secure user privacy
 - **Biometric cryptosystems:** combination of cryptographic keys and biometric data (e.g., fuzzy vault, fuzzy commitment)
 - **Transform-based schemes:** application of non-invertible functions to the biometric data (e.g., cancelable biometrics)
- **Dealing with variability** is the main challenge in this field

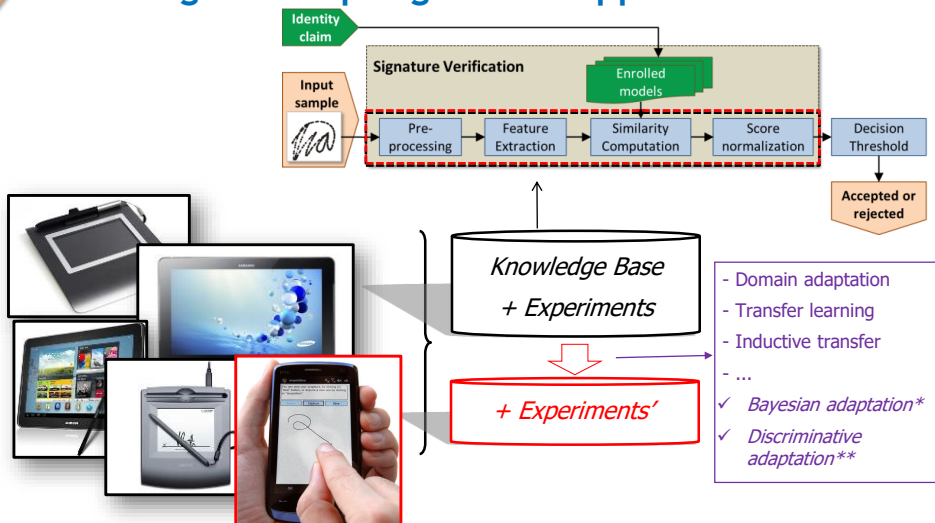
P. Campisi, E. Maiorana, J. Fierrez, J. Ortega-Garcia and A. Neri, "Cancelable Templates for Sequence Based Biometrics with Application to On-Line Signature Recognition", *IEEE Trans. on SMC-A*, May 2010.

M. Gomez-Barrero, J. Galbally, A. Morales and J. Fierrez, "Privacy-Preserving Comparison of Variable-Length Data with Application to Biometric Template Protection", *IEEE Access*, June 2017.

M. Gomez-Barrero, E. Maiorana, J. Galbally, P. Campisi and J. Fierrez, "Multi-Biometric Template Protection Based on Homomorphic Encryption", *Pattern Recognition*, July 2017.

59

The Future of Behavioral Biometrics Challenge 1: Adapting to New Application Scenarios



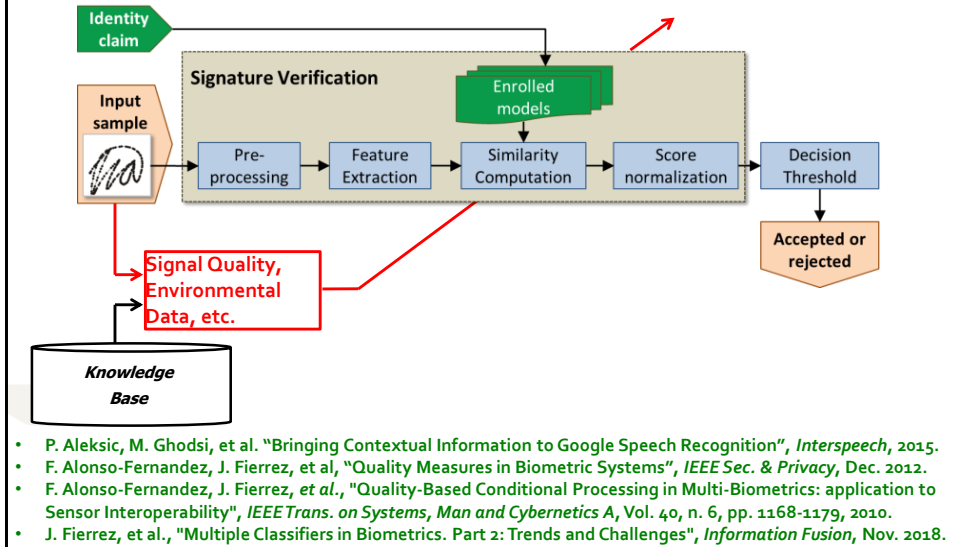
* J. Fierrez-Aguilar, D. Garcia-Romero, J. Ortega-Garcia and J. Gonzalez-Rodriguez, "Bayesian adaptation for user-dependent multimodal biometric authentication", *Pattern Recognition*, August 2005.

**J. Fierrez-Aguilar, D. Garcia-Romero, J. Ortega-Garcia and J. Gonzalez-Rodriguez, "Adapted user-dependent multimodal biometric authentication exploiting general information", *Pattern Recognition Letters*, December 2005.

60

The Future of Behavioral Biometrics

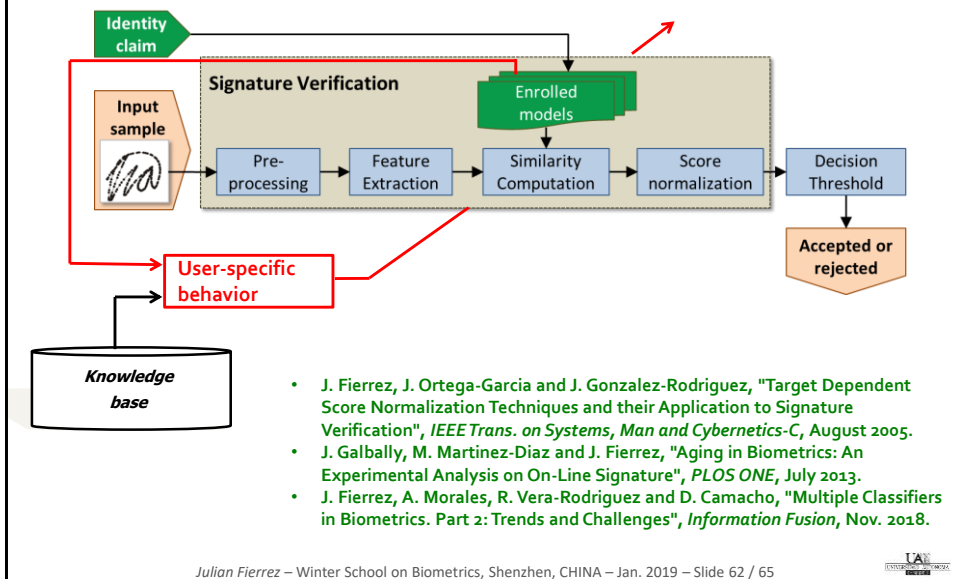
Challenge 2: Incorporating Contextual Information



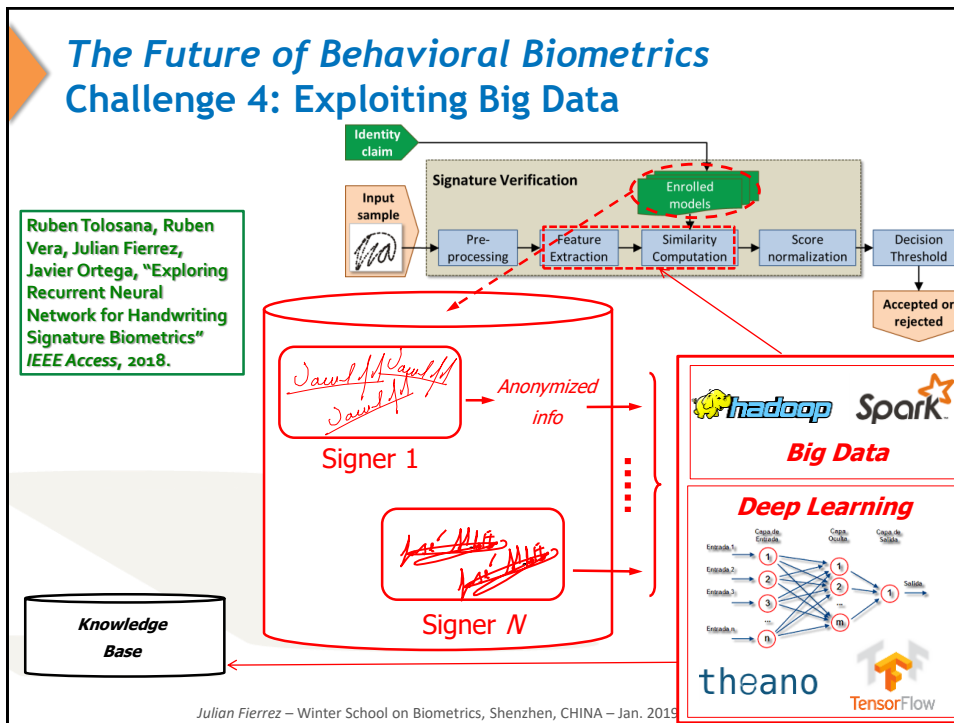
61

The Future of Behavioral Biometrics

Challenge 3: Adapting to the User (e.g., Aging)



62



63

Signature Biometrics: Conclusions

Revocability Easy of use, user acceptance Less sensor-interoperability issues Easy to integrate at low-cost Continuous ID	User intra-variability Multi-sample training Model updating Multilevel strategies Data scarcity
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- Mature technology
- Major role in on-line, mobile, and legacy applications
- User convenience to drive application development
- Room for substantial industry-applicable research

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64

Signature Biometrics

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<http://atvs.ii.uam.es/fierrez>

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