Robotic Arm Motion for Verifying Signatures



Moises Diaz[1] Miguel A. Ferrer[2] Jose J. Quintana[2]

[1]Universidad del Atlantico Medio, Spain

[2]Instituto para el Desarrollo Tecnológico y la Innovación en Comunicaciones
Universidad de Las Palmas de Gran Canaria, Spain

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Outline

1. **Introduction**
2. Virtual Skeletal Arm model
3. Robotic/Anthropomorphic Feature Extraction
4. Results
5. Conclusions

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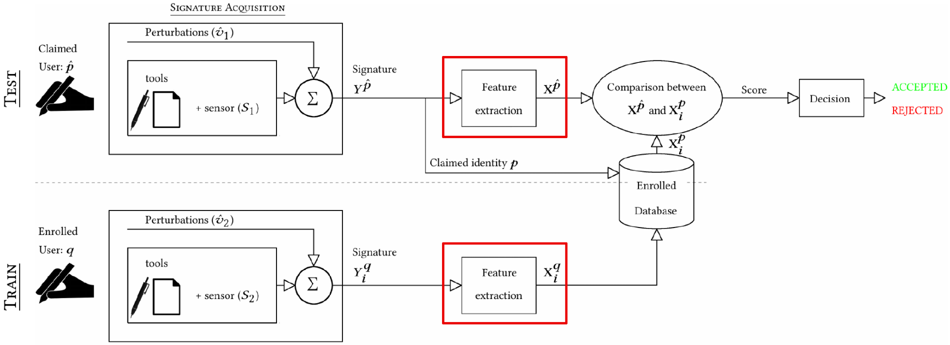
Automatic Signature Verification



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On-line: Local features

- The signature is analyzed locally
- The signature is represented through timing sequences or functions in diverse domains
- Basic functions: obtained directly from the digital tablet
  - Position: x_n, y_n
  - Pressure: p_n
  - Pen-tip angles from the writing area: ϕ_n, ψ_n
- Extended functions
  - Tan angle: $\theta_n = \tan^{-1}(\dot{y}_n/\dot{x}_n)$
  - velocity (module): $v_n = \sqrt{\dot{x}_n^2 + \dot{y}_n^2}$
  - log-radius curvature: $\rho_n = \log(1/k_n) = \log(v_n/\dot{\theta}_n)$
  - acceleration (module): $a_n = \sqrt{t_n^2 + c_n^2} = \sqrt{\dot{v}_n + v_n^2\theta_n^2}$
  - Time derivatives of the above functions
  - ...

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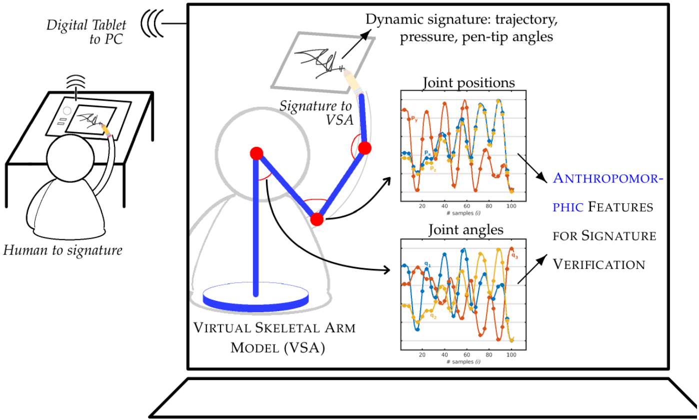
Our proposal

A novel feature space for on-line signature verification



Main characteristics

- Based on the arm posture when signing: joint *angles* and *positions*
- Physical meaning, simple, fast and verifiable solution
- Designing of a Virtual Skeletal Arm (VSA) model
- Mathematical fundamentals from *forward* and *direct* kinematic in robotics

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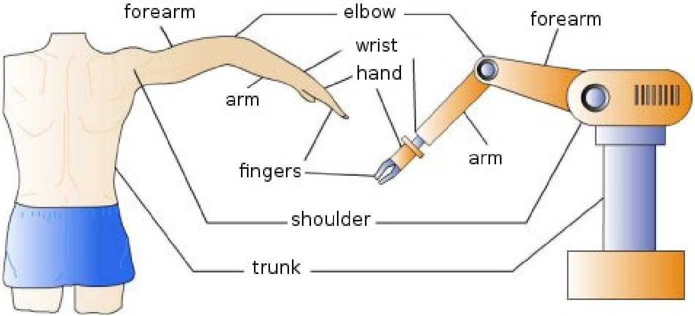
Virtual Skeletal Arm (VSA) model

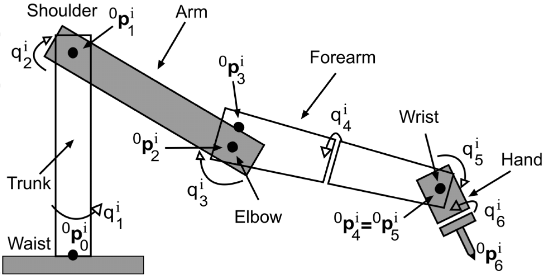
Similarities with the theoretical model



Virtual Skeletal Arm (VSA) model

Proposal Architecture based on an anthropomorphic robot

	Position-based Features	Angle-based Features
Waist	${}^0\mathbf{p}^i_0$	q^i_1
Shoulder	${}^0\mathbf{p}^i_1$	q^i_2
Elbow	${}^0\mathbf{p}^i_2, {}^0\mathbf{p}^i_3$	q^i_3, q^i_4
Wrist	${}^0\mathbf{p}^i_4, {}^0\mathbf{p}^i_5$	q^i_5, q^i_6
Pen-tip	${}^0\mathbf{p}^i_6$	



We got two sets of timing functions: joint **angle** movements and joint **position**

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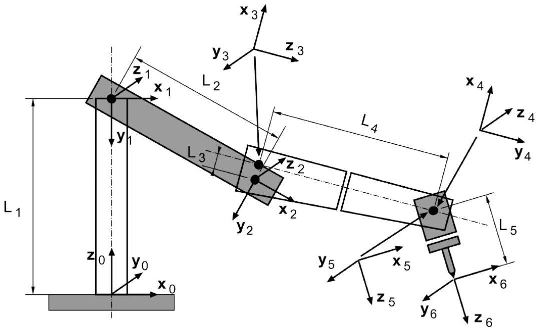
Coordinate Frames in the VSA



Relationship among them by homogeneous transformation matrices. E.g.:

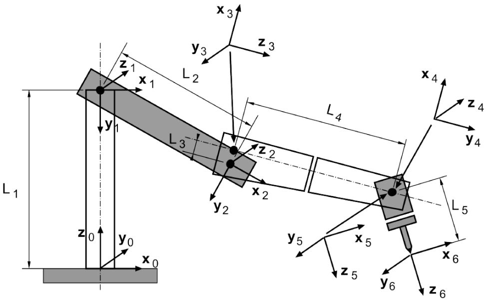
$$^{0}\mathbf{T}_{6}^{i} = \begin{pmatrix} n_x^i & o_x^i & a_x^i & p_x^i \\ n_y^i & o_y^i & a_y^i & p_y^i \\ n_z^i & o_z^i & a_z^i & p_z^i \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Forward Kinematics

- Goal: To calculate the pose of the coordinate frames (CFs) relating to the VSA model, as a function of its joints angles $\mathbf{Q}(q_k^i)$.
- Strategy: Denavit-Hartenberg (DH) algorithm is widely used.

Table: DH parameters, $\mathbf{DH}_k^i$

Joint k	δ_k^i	d_k	a_k	α_k
1	q_1^i	L_1	0	$-\frac{\pi}{2}$
2	$q_2^i - \frac{\pi}{2}$	0	L_2	0
3	q_3^i	0	L_3	$-\frac{\pi}{2}$
4	q_4^i	L_4	0	$\frac{\pi}{2}$
5	q_5^i	0	0	$-\frac{\pi}{2}$
6	q_6^i	L_5	0	0



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Forward Kinematics

$$^{k-1}\mathbf{T}_k^i =$$

$$\begin{pmatrix} c\left(\delta_k^i\right) & -c\left(\alpha_k\right)s\left(\delta_k^i\right) & s\left(\alpha_k\right)s\left(\delta_k^i\right) & a_k c\left(\delta_k^i\right) \\ s\left(\delta_k^i\right) & c\left(\alpha_k\right)c\left(\delta_k^i\right) & -s\left(\alpha_k\right)c\left(\delta_k^i\right) & a_k s\left(\delta_k^i\right) \\ 0 & -s\left(\alpha_k\right) & c\left(\alpha_k\right) & d_k \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

$$^{0}\mathbf{T}_6^i = {}^{0}\mathbf{T}_1^i \cdot {}^{1}\mathbf{T}_2^i \cdot {}^{2}\mathbf{T}_3^i \cdot {}^{3}\mathbf{T}_4^i \cdot {}^{4}\mathbf{T}_5^i \cdot {}^{5}\mathbf{T}_6^i \quad (2)$$

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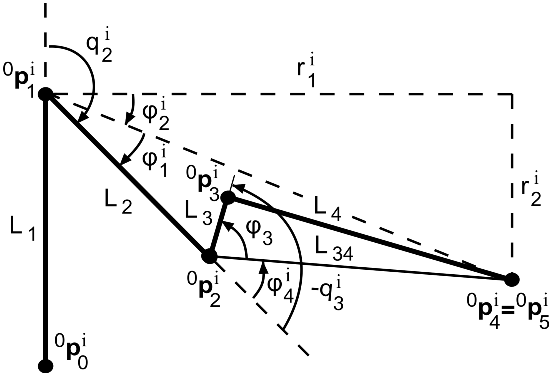
Inverse Kinematics

- Goal: To deduce the joint angle-based features, $\mathbf{Q}(q_k^i)$, based on the pose of the pen attached to the end of the model.
- Strategy: kinematic decoupling. Firstly q_1^i, q_2^i, q_3^i, secondly, q_4^i, q_5^i, q_6^i



Kinematics Validation

The function will be availble soon

For researching purposes, we share our anthropomorphic feature extractor

Developed in Matlab language

```
angles = pos2ang(x,y,z)
```

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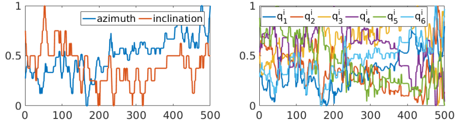
Experimental protocol

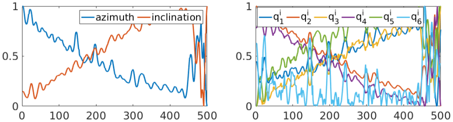
- Database: MCYT-100: 25 genuine, 25 forgeries, 100 users
- Train: first T enrolled signature
- Test:
  - FAR: remaining genuine signatures: $(25 - T) \times 100$ scores
  - FRR: Random Forgery (RF): 1st testing genuine signature from the other users: $99 \times 100 = 9900$ scores
  - FRR: Skilled Forgery (SF): all available: $25 \times 100 = 2500$ scores
- **Features:** $\mathbf{Q}(q_k^i), \forall k \in 1, \ldots 6$ ⇽OUR CONTRIBUTION
- ASV: Dynamic Time Warping
- Performance: EER and DET curve

Pen-tip angles for orientating the CF $\{S_6\}$

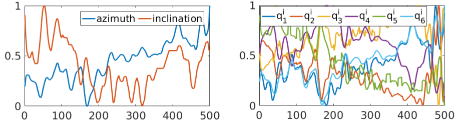
Raw angles (θ_r^i, ϕ_r^i), and the corresponding joint angles



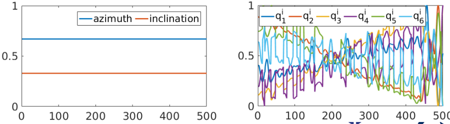
Estimated angles (θ_e^i, ϕ_e^i), and the corresponding joint angles



Smoothed angles (θ_s^i, ϕ_s^i), and the corresponding joint angles



Fixed angles (θ_f^i, ϕ_f^i), and the corresponding joint angles



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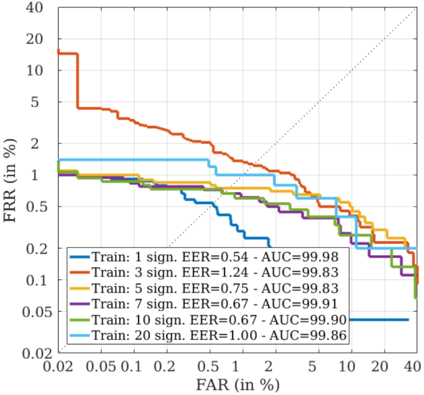
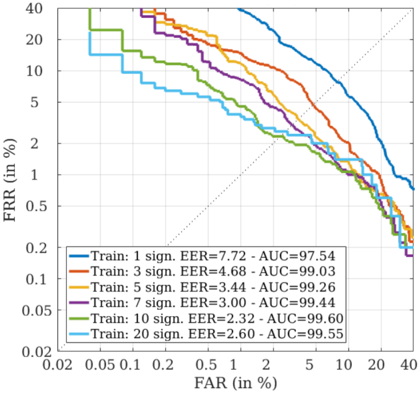
Performance results for different number of signatures to train

MCYT-100, only angle-based features and a DTW verifier



(a) Random Forgeries



(b) Skilled Forgeries

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Comparison with on-line ASV, using five signatures to train and the MCYT-100. Performance in ERR (%).

Year	**Method**	**RF**	**SF**
2016	DTW+VQ [14]	-	1.55
2017	WP+BL DTW fusion [15]	-	2.76
2016	GMM+DTW [16]	-	3.05
2018	**Angular Robotic Features + DTW**	**0.75**	**3.44**
2017	$\Sigma\Lambda$ + DTW [3]	1.01	3.56
2014	Histogram+Manhattan [4]	1.15	4.02
2017	Symbolic Rep [17]	2.40	5.70

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Conclusions

- Framework to transform the on-line signature samples into a new feature space
- Mathematical basis for the designing Virtual Skeletal Arm (VSA) models
- Using robotic concepts to deduce the 3D movement from the pen-tip
- Features with physical meaning, simple, fast and with a verifiable solution
- Good results with angle-based features for on-line ASV

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Future works

- Combination of position-based and angle-based robotic/anthropomorphic features
- Use more signature database and verifiers
- Modeling the anatomy of the hand: the finger movement supported by the wrist can be also relevant
- Adapting robotic features for off-line ASV

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