Joint Intensity and Spatial Metric Learning for Robust Gait Recognition

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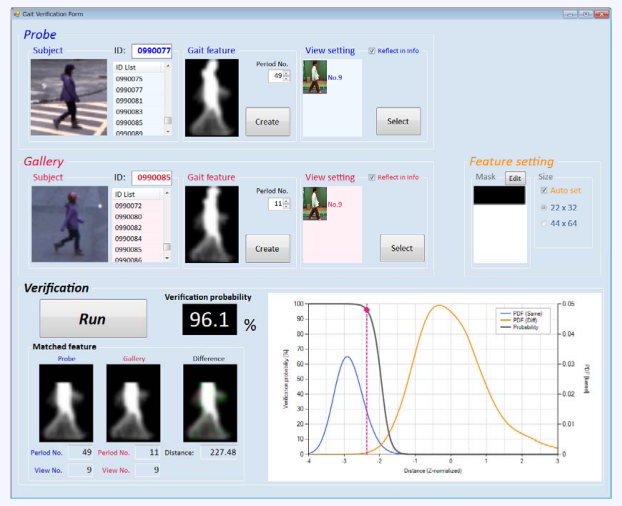
Introduction

■ Background

➢ **Gait** is biometrics at a distance.

➢ Applications:
- Criminal investigation
- Surveillance
- Access control

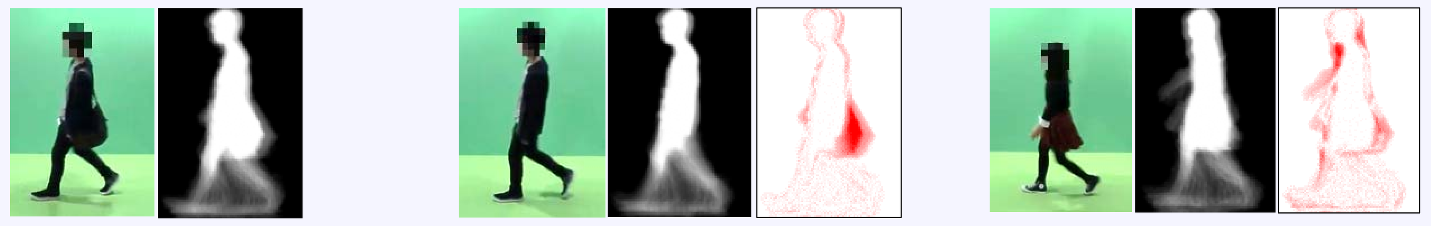


Gait verification system [Iwama+ 2013]

■ Challenges

➢ Intra-class appearance changes

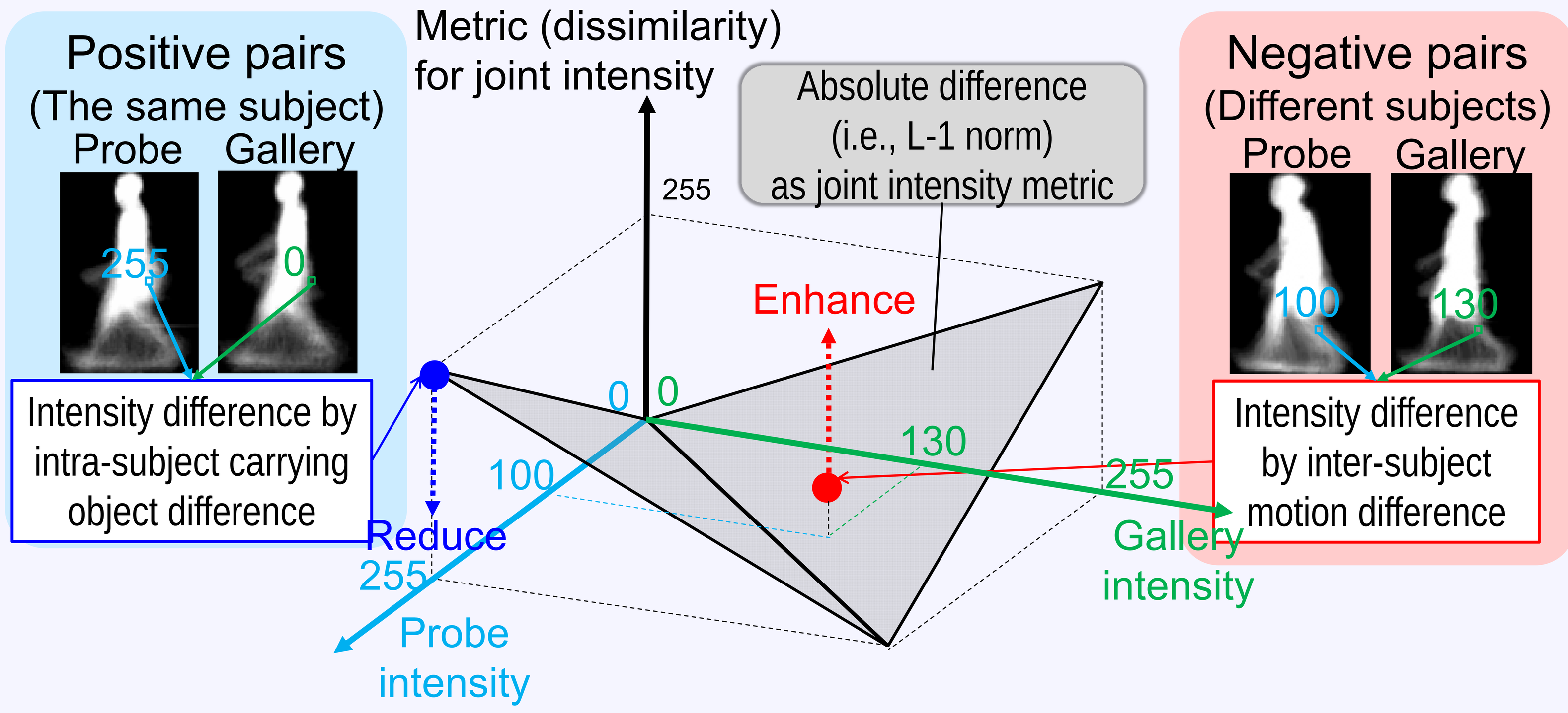
l_1-norm with gait energy image (GEI) [Han+ 2006]



Probe (w/ bag) | True match gallery (w/o bag) | False match gallery (w/o bag)

■ Key idea

➢ Learn a metric for joint intensity for better discrimination



■ Related work

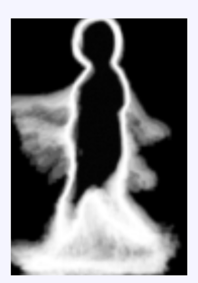
➢ Spatial metrics
- Support vector machine (SVM)
- Mahalanobis distance

$$d(\boldsymbol{v}^P,\boldsymbol{v}^G;\boldsymbol{w}_S)=\sum_{i=1}^{N_S} w_{S,i}\left|v_i^P-v_i^G\right|$$

$$d(\boldsymbol{v}^P,\boldsymbol{v}^G;M)=\left(\boldsymbol{v}^P-\boldsymbol{v}^G\right)^T M\left(\boldsymbol{v}^P-\boldsymbol{v}^G\right)$$

✓ Subtraction form, monotonic increase

➢ Intensity metrics
- Gait entropy image (GEnI) [Bashir+ 2009]
- Masked GEI [Bashir+ 2010]
- Gait energy response function [Li+ 2016]



GEnI

Joint intensity and spatial metric learning

■ Representation of dissimilarity measure

$$D(\boldsymbol{v}^P,\boldsymbol{v}^G;\boldsymbol{w}_S,\eta)=\sum_{i=1}^{N_S} w_{S,i}\,\eta(v_i^P,v_i^G)$$

Spatial weight

Dissimilarity metric for joint intensity

(e.g., $\eta(p,q)=|p-q|$ for l_1-norm)

$$\eta(p,q)=\boldsymbol{x}_{(p,g)}^T\boldsymbol{w}_I$$

Indicator vector

Joint intensity metric

	Gallery intensity g →		
Probe intensity p ↓	$w_{I,(0,0)}$	…	
	$w_{I,(I_{\max},0)}$		$w_{I,(I_{\max},I_{\max})}$

$$\boldsymbol{w}_I=[w_{I,(0,0)},\cdots,w_{I,(0,I_{\max})},\cdots,w_{I,(I_{\max},0)},\cdots,w_{I,(I_{\max},I_{\max})}]^T$$

$$\boldsymbol{x}_{(p,g)}=[\delta_{p,0}\delta_{g,0},\cdots,\delta_{p,0}\delta_{g,I_{\max}},\cdots,\delta_{p,I_{\max}}\delta_{g,0},\cdots,\delta_{p,I_{\max}}\delta_{g,I_{\max}}]^T$$

➢ Dissimilarity measure as bilinear form

$$D(\boldsymbol{v}^P,\boldsymbol{v}^G;\boldsymbol{w}_S,\boldsymbol{w}_I)=\sum_{i=1}^{N_S}\sum_{j=1}^{N_I} w_{S,i}w_{I,j}X_{(v_i^P,v_i^G),j}=\boldsymbol{w}_S^T X_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}\boldsymbol{w}_I$$

■ Metric learning

➢ Linear SVM

Hinge loss function

$$J(\boldsymbol{w}_S,\boldsymbol{w}_I)=\frac{1}{2}\|\boldsymbol{w}_S\|^2+\frac{1}{2}\|\boldsymbol{w}_I\|^2+C\sum_{(\boldsymbol{v}^P,\boldsymbol{v}^G,t)\in S} l(\boldsymbol{w}_S^T X_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}\boldsymbol{w}_I+b,t)$$

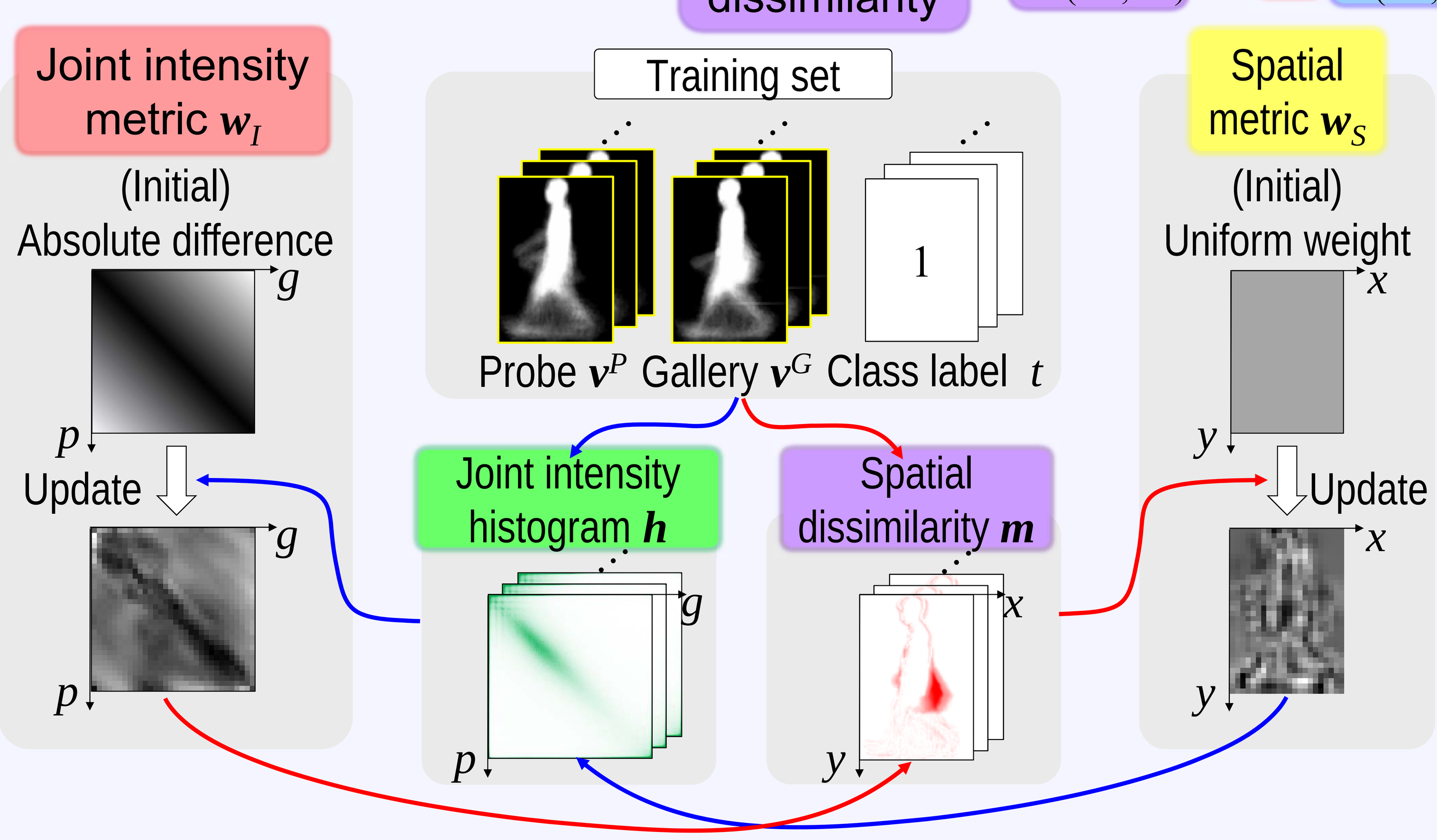
➢ Alternate optimization

$$J_I(\boldsymbol{w}_I)=\frac{1}{2}\|\boldsymbol{w}_I\|^2+C\sum_{(\boldsymbol{v}^P,\boldsymbol{v}^G,t)\in S} l(\boldsymbol{h}_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}^T\boldsymbol{w}_I+b,t)\to\min$$

Joint intensity histogram $\quad \boldsymbol{h}_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}=X_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}^T\boldsymbol{w}_S$

$$J(\boldsymbol{w}_S)=\frac{1}{2}\|\boldsymbol{w}_S\|^2+C\sum_{(\boldsymbol{v}^P,\boldsymbol{v}^G,t)\in S} l(\boldsymbol{m}_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}^T\boldsymbol{w}_S+b,t)\to\min$$

Spatial dissimilarity $\quad \boldsymbol{m}_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}=\boldsymbol{w}_I^T X_{(\boldsymbol{v}^P,\boldsymbol{v}^G)}^T$



Experiments

■ Data sets

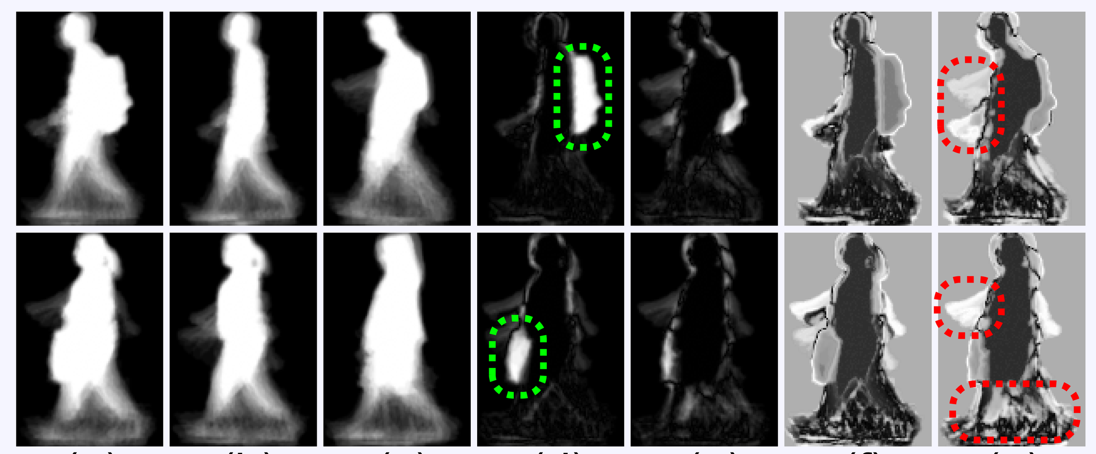
➢ OUTD-B [Makihara+ 2012]
- #Clothes variations: 32
- #Subjects: 68 (20 for training, 48 for test)

Available at:

➢ OULP-Bag-β
- Data collection in long-run exhibition [Makihara+ 2016]
- Carrying status variation in the wild
- #Subjects: 2,070 (1,034 for training, 1,036 for test)

■ Learnt metrics and matching examples (OULP-Bag-β)

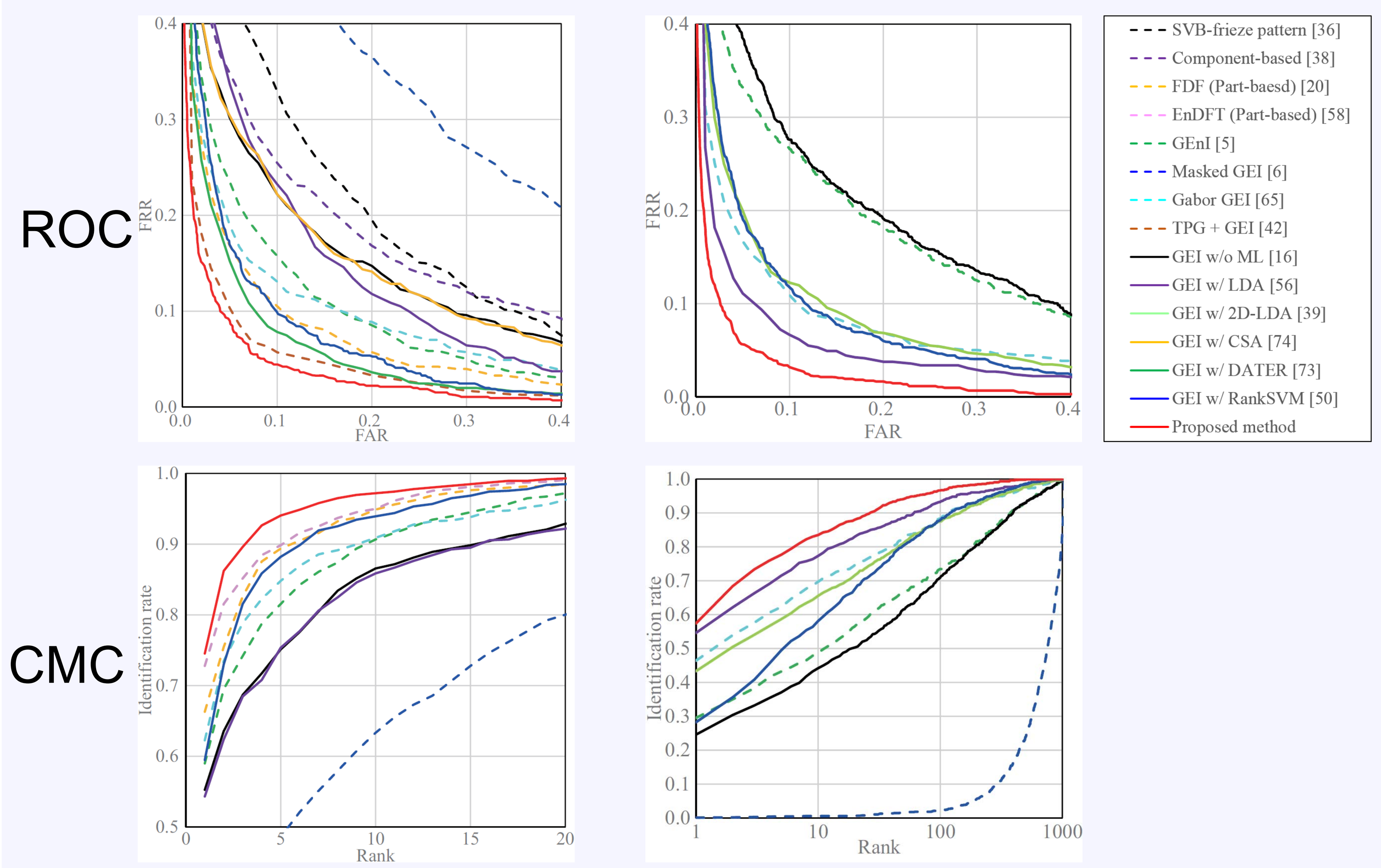
GEI | GEnI | Spatial weight | JIM for l_1-norm | JIM for GEnI | Learnt JIM (Proposed)



(a) | (b) | (c) | (d) | (e) | (f) | (g)

(a) Probe (w/ bag)
(b) Gallery (genuine)
(c) Gallery (imposter)
(d) l_1-norm for (a)(b)
(e) l_1-norm for (a)(c)
(f) JIM for (a)(b)
(g) JIM for (a)(c)

■ Comparison with state-of-the-art



OUTD-B | OULP-Bag-β