A Deformation and Lighting Insensitive Metric for Face Recognition

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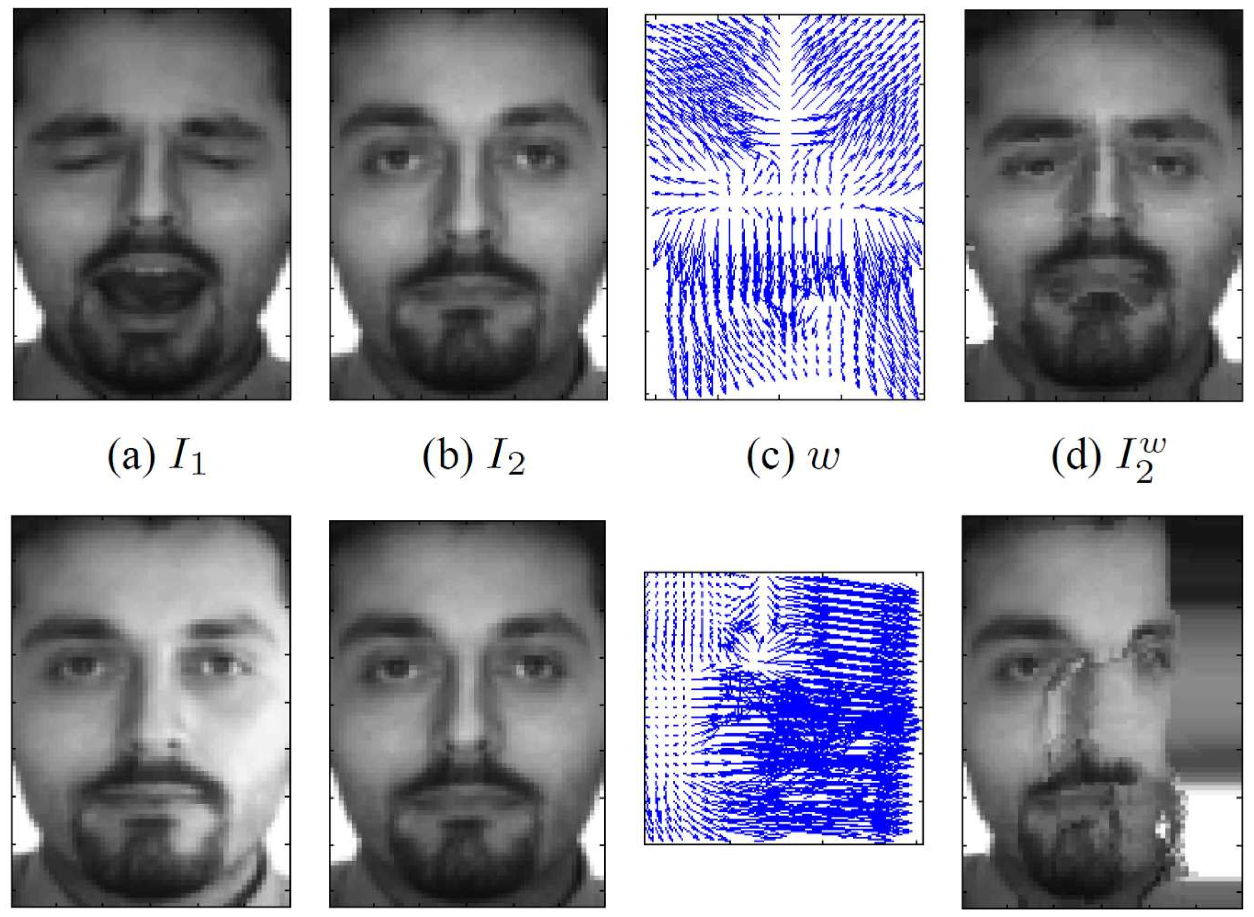
This research was funded by the Office of the Director of National Intelligence (ODNI), Intelligence Advanced Research Projects Activity (IARPA), through the Army Research Laboratory (ARL). All statements of fact, opinion or conclusions contained herein are those of the authors and should not be construed as representing the official views or policies of IARPA, the ODNI, or the U.S. Government.

Optical Flow for Face Recognition

Goal: Find a flow field to determine dense correspondences between images.

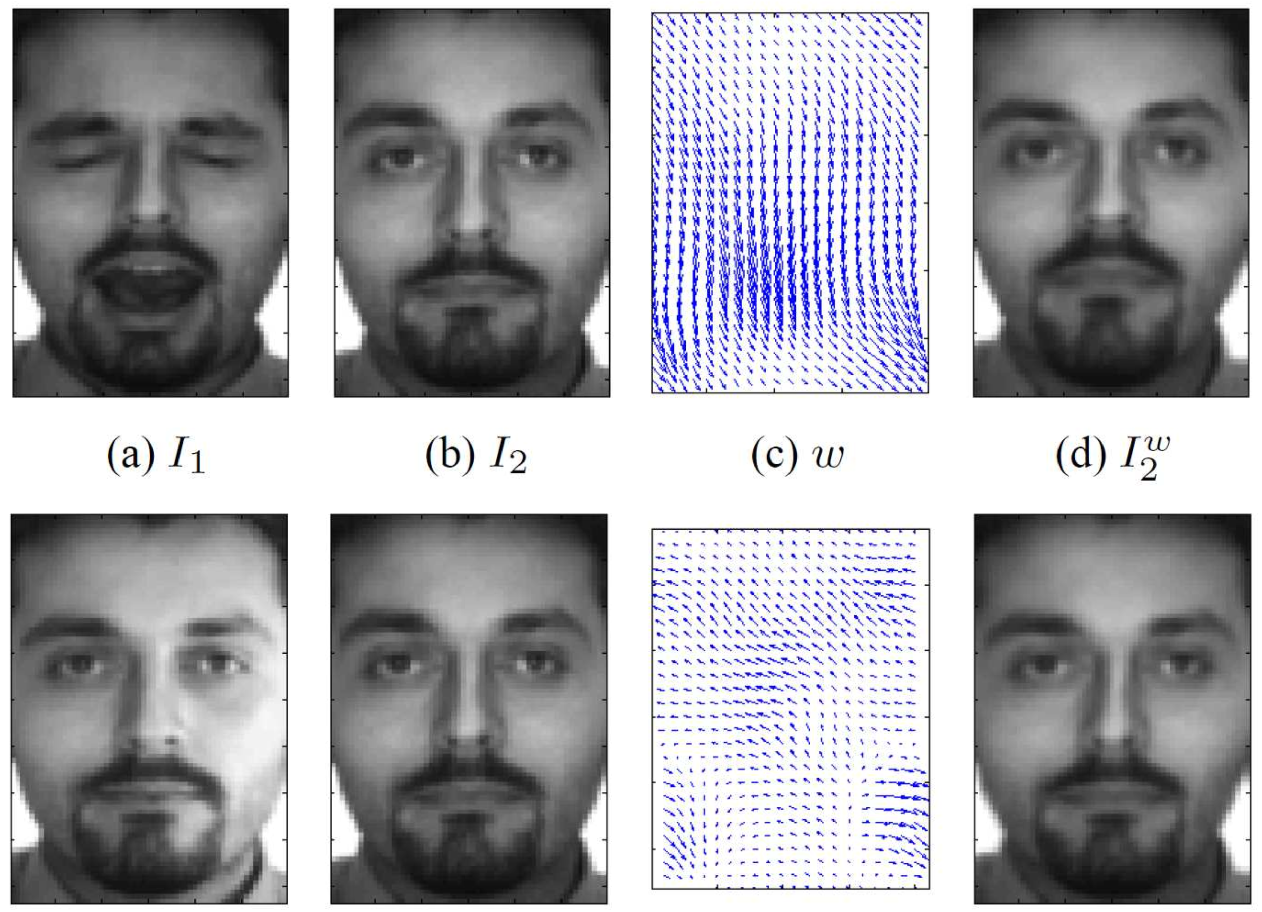
w : the flow from I_1 to I_2
I_2^w : I_2 warped backwards along w to attempt to match I_1

Poor results are achieved when traditional optical flow is used.



(a) I_1 (b) I_2 (c) w (d) I_2^w
(e) I_1 (f) I_2 (g) w (h) I_2^w

The flow calculated with our proposed method is more stable.



(a) I_1 (b) I_2 (c) w (d) I_2^w
(e) I_1 (f) I_2 (g) w (h) I_2^w

The New Deformation and Lighting Insensitive (DLI) Metric

Goal: Define a metric that is insensitive to expression and lighting changes in facial images.

$$E_{\mathrm{DLI}}(w) = (1-\lambda)E_b(w) + \lambda E_r(w)$$

Photometric term :
$$E_b(w) = \frac{1}{2}\sum_{ij} \frac{\|\nabla(I_2^w - I_1)\|^2}{\|\nabla I_1\|^2 + \epsilon^2} = \frac{1}{2}\sum_{ij} (E^x_{b_{ij}})^2 + (E^y_{b_{ij}})^2$$

- Invariant to multiplication by a scalar and addition by a constant.
- Insensitive to changes caused by the effects of lighting variation in 3D scenes, ex: changing the location of a light can magnify or weaken the gradient at the edge of a polyhedron, as the two sides forming the edge are exposed differently to the light.

Regularization term :
$$E_r(w) = \frac{1}{2}\langle K^{-1}w,\ w\rangle_G = \frac{1}{2}\sum_{ij} (E^x_{r_{ij}})^2 + (E^y_{r_{ij}})^2$$

- K is a symmetric positive definite matrix
- G is a generalized inner product defined on *MxNx2* structures

Optimization

Use a modified gradient descent algorithm to minimize $E_{\mathrm{DLI}}(w)$.

Sobolev Gradient[1]: $\nabla_K E = K\nabla E$

- Smoother, results in superior rates of convergence.

Optimize over a dual variable α:

$$w_n = K\alpha_n \quad \text{(this is a convolution)}$$
$$\alpha_{n+1} = \alpha_n - \Delta t \cdot \nabla E(w_n)$$

Learning for Improved Results

Use Maximum Likelihood estimation to learn typical Gaussian distributions through the 4D cost vectors between same person image pairs at each pixel location from:

$$\vec{E}_{ij} = [E^x_{b_{ij}}\ E^y_{b_{ij}}\ E^x_{r_{ij}}\ E^y_{r_{ij}}]$$

$$P(\vec{E}^{\mathrm{new}}_{ij}) = \frac{\exp\left(-\frac{1}{2}\left[(\vec{E}^{\mathrm{new}}_{ij} - \overline{\vec{E}_{ij}})^T \Gamma_{ij}^{-1} (\vec{E}^{\mathrm{new}}_{ij} - \overline{\vec{E}_{ij}})\right]\right)}{(2\pi)^{4/2}\sqrt{det(\Gamma_{ij})}}$$

Assume pixel independence:

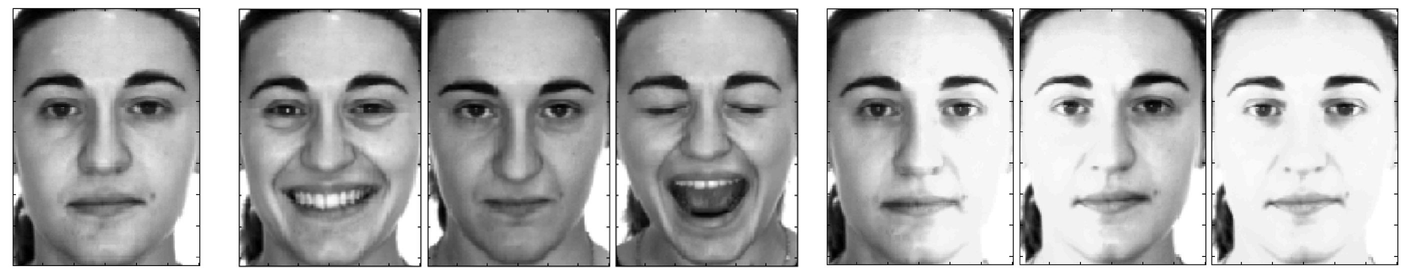
$$P_{\mathrm{same}}(\vec{E}^{\mathrm{new}}(w)) = \prod_{ij} \vec{E}^{\mathrm{new}}_{ij}$$

Learn a separate model for different person image pairs, and use the final similarity measure to maximize:

$$S(I_1, I_2) = \frac{P_{\mathrm{same}}(\vec{E}^{\mathrm{new}}(w))}{P_{\mathrm{diff}}(\vec{E}^{\mathrm{new}}(w))}$$

Experiments

The AR Face Database[2] with variations in expression and lighting:



Identification of unknown face is determined by the gallery image resulting in the lowest matching cost.

Cost Function	*Expression*	*Lighting*	*Overall*
Direct	82.0%	96.0%	89.0%
After Learning	89.6%	98.9%	94.3%
Smile gallery After Learning	86.8%	91.2%	89.0%
Borders removed After Learning	85.1%	96.4%	90.7%

Variation	*Accuracy*	*Variation*	*Accuracy*
Smile	97.6%	Left light	98.8%
Frown	91.6%	Right light	99.6%
Scream	79.6%	Both lights	98.4%

References:
[1]J. W. Neuberger. *Sobolev Gradients and Differential Equations, 2nd Edition*. Springer, 2010.
[2]A. Martinez and R. Benavente. The AR Face Database. *CVC Technical Report #24*, 1998.