Thermal Handprint Analysis for Forensic Identification using Heat-Earth Mover's Distance

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Introduction

In recent years, handprint-based recognition system has been widely applied in forensic science. However, existing identification systems are nearly based on the handprints that could be easily prevented. In contrast to earlier works, we exploit the thermal handprint dissimilarity measure, called **Heat-Earth Mover's Distance (HEMD)**. It is designed to classify heat-based handprints that can be obtained even when the subject wears a glove.

Our objective is to develop a system that performs a forensic identification using heat-based handprints

1. Thermal handprints made without the glove
2. Thermal handprint made with the glove

Background and Motivation

Existing forensic identification systems:

1. DNA fingerprinting (blood, skin, hair, saliva) uses a length of the strands of the DNA molecules with repeating base pair patterns by restricting fragment length polymorphism (RFLP)
2. Odor analysis uses a chemical analysis of perfume components by gas chromatography (GC)
3. Voice analysis using Gaussian mixture speaker models achieved an accuracy of 82.8% (Reynolds *et al*).
4. **Fingerprint / handprint** uses a minutiae-based structural matching. Previously, handprint-based verification system made by integrating hand geometry feature and fingerprint feature achieved **an accuracy of 97%** (Yan *et al*).

Limitations:

1. DNA fingerprinting is not available in all forensic scenes
2. For odor analysis, the result depends on the existence of perfume and type of fabric containing perfume residue.
3. Voice analysis can be interrupted by overlapping speech and low-signal-to-noise ratio.
4. Fingerprint / handprint is **the most promising approach but can be prevented using glove**.

Solution:

1. **Thermal imaging**: fast, safe, and accurate non-contact measurement of temperature
2. Preservation of the scene since it is invisible and has **no influence from indirect contact** or lubrication.
3. Expansion of the target range since every object emits infrared energy.

Figure 1. 3-D illustration of thermal handprint (made with 3 seconds of pressing the surface) with respect to time.

Proposed Method

Figure 2. Heat-Earth Mover's Distance Framework

Feature Extraction

Figure 3. All images are cropped 192X192 pixel dimension and converted into gray-scale images. Then, 2-D filter is applied to remove the noise. **Sobel filter** is used for an edge detection algorithm that computes an approximation of the gradient of the image intensity functions. Then, **principal component analysis (PCA)** estimates the angle of the major axis of variation and rotates the image according to the variation. Lastly, rotated images are transformed into point distributions.

Earth Mover's Distance

Figure 4. EMD is a minimal cost that must be paid to transform one distribution into another. When colored points are in correspondence, cost is defined by Euclidean Distance

$$\begin{aligned} \text{Target } X &= \{(x_1, w_{x_1}) \dots (x_m, w_{x_m})\}, 1 \leq i \leq m \\ \text{Training } Y &= \{(y_1, w_{y_1}) \dots (y_n, w_{y_n})\}, 1 \leq j \leq n \\ \text{Ground distance } D &= [d_{ij}] \\ \text{Flow } F &= [f_{ij}] \end{aligned}$$

$$\begin{aligned} \text{HEMD}(X, Y, F) &= \min \left(\sum_{i=1}^m \sum_{j=1}^n f_{ij} d_{ij} \right) \\ f_{ij} &\geq 0; 1 \leq i \leq m, 1 \leq j \leq n \\ \sum_{i=1}^m w_{x_i} &= \sum_{j=1}^n w_{y_j} \\ \sum_{j=1}^n f_{ij} &\leq w_{x_i}; 1 \leq i \leq m \\ \sum_{i=1}^m f_{ij} &\leq w_{y_j}; 1 \leq j \leq n \\ \sum_{i=1}^m \sum_{j=1}^n f_{ij} &= \min \left(\sum_{i=1}^m w_{x_i}, \sum_{j=1}^n w_{y_j} \right) \end{aligned}$$

Advantages:

1. Good for image matching that deals with occlusions and clutter.
2. Is a true metric if the ground distance is metric and total weights of two signatures are equal

Figure 5. our task is to transport the points from the target X to training Y with the least cost. Second equation allows the overall weight of points in X to be equal to the overall weight of points in Y. Thus, weight normalization is not needed.

Experiment

Setup:

1. 20 participants had two types of sample, Standard-Handprint (SH) and Glove-Handprint (GH)

Sample Type	Per 1 subject (#)	Total (#)
SH	40	800
GH	20	400

2. **Leave-one-out-cross-validation (LOOCV)** is used to estimate how accurately a predictive model will perform.
3. **K nearest neighbor classification (kNN)** is used and our distance function is HEMD and k equals 5.

Results:

	ACC (%)	BAC (%)	F1 (%)	AUC (%)	EER (%)
SH	94.13	94.49±8.59	94.49	95.69±6.92	1.07±0.94
GH	92.00	92.50±9.09	92.50	98.50±2.40	3.29±2.49

Table 1. ACC is an average accuracy, BAC is balanced accuracy, and F1 is F-measure accuracy.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
A	16	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
B	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	0	0	15	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
D	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
E	1	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	2	18	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	0	18	0	0	0	0	0	0	0	2	0	0	0	0
I	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0
K	1	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0
L	0	0	0	2	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0	0	0	0	17	0	1	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0
Q	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	0	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0
T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36

Table 2. Confusion matrix of SH is on right and GH is on left

Figure 6. Receiver operating characteristics (ROC) of 10 out of 20 subjects for SH and GH. It is an effective method to assess how the classifier performs in the region of high sensitivity and high specificity. The closer the curve follows the top-left, more accurate the test is. Area under the ROC curve (AUC) is provided to show how well a parameter can distinguish a target

Figure 7. Equal error rate (EER) when acceptance error and rejection error become equal. The lower the EER, the higher the accuracy. Relatively low EER of SH indicates that SH is more stable than using GH

Conclusion

Comprehensive experiments are conducted and achieved the accuracy of 94.13% for SH and 92.00% for GH. The performance indicates that HEMD is secure and feasible biometric system

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