Multi-touch Authentication Using Hand Geometry and Behavioral Information

Aokun Chen

Related Work

- Gait Recognition
- Keystroke/Mouse dynamics
- Gesture based authentication

Threat Model and Assumption

- The adversary may or may not observe the unlock gesture:
  - Zero-effort Attack
  - Smudge Attack
  - Shoulder Surfing Attack
  - Statistical Attack
- The adversary does not have the capability to produce an apparatus with the exact same hand geometry while also being able to observe and replicate the behavior characteristics

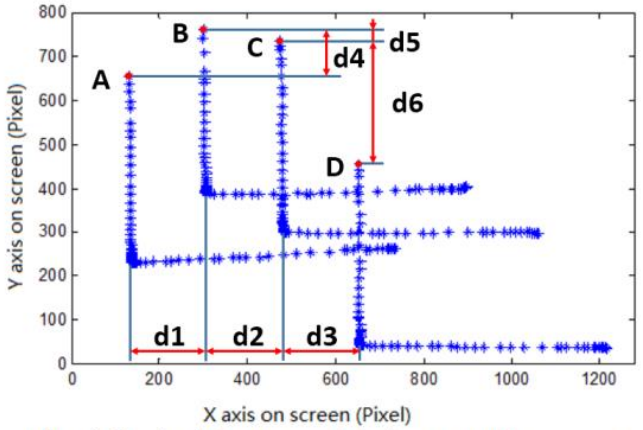
Methodology

- TFST gestures:
  - “Touching with Fingers Straight and Together”

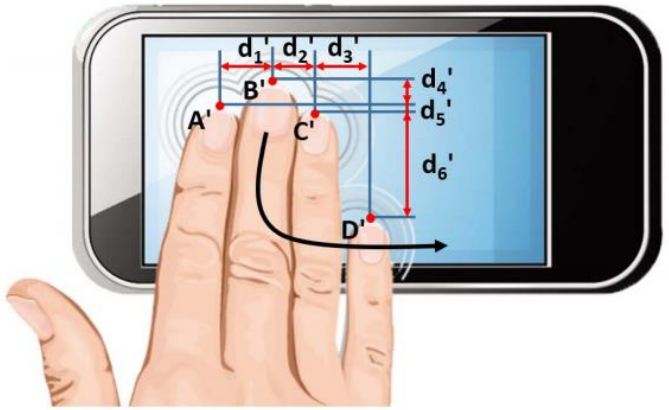
a. 2-finger Z swipe b. 3-finger swipe c. 4-finger L swipe

Methodology

- TFST Gesture features:
  - Multi-touch Traces
  - Physiological Features
    - 12 distances
  - Behavioral Features
    - Length, time, velocity, tool, touch, pressure, angle
    - 52 for 4 fingers, 39 for 3 fingers 26 for 2 fingers



a. Physiological features of 4-finger TFST gesture



b. Real features of hand geometry

Data Collection

- Android application on a smartphone
- 161 subjects:
  - 131 sophomores
  - 18 master and PhD students
  - 12 faculty members or staffs
- 2 months, 7-session data collection
- 144 hand image data

Feature Analysis

- Discernibility of Physiological Features in TFST Gestures

TABLE I. CORRELATION COEFFICIENTS (CC) BETWEEN FEATURES OF HAND GEOMETRY AND FEATURES OF TFST GESTURE, FEATURE # ARE THE SAME AS THOSE GIVEN IN SECTION III-B

Feature ID	**1**	**2**	**3**	**4**	**5**	**6**
CC	0.75	0.92	0.82	0.73	0.88	0.89
Feature ID	**7**	**8**	**9**	**10**	**11**	**12**
CC	0.70	0.80	0.76	0.70	0.53	0.87

Feature Analysis

- Feature Selection
  - Fisher Score:

$$\text{Fisher(k)} = \frac{\tilde{S}_b^k}{\tilde{S}_t^k}$$

$$S_b = \Sigma_{k=1}^{c} P_k (\tilde{\mu}_k - \check{\mu})(\tilde{\mu}_k - \check{\mu})^T$$

$$S_t = \Sigma_{k=1}^{c} P_k \Sigma_{x_i^k \in c_k} \frac{1}{n_k} (x_i^k - \tilde{\mu}_k)(x_i^k - \tilde{\mu}_k)^T$$

Feature Analysis

- Feature Selection

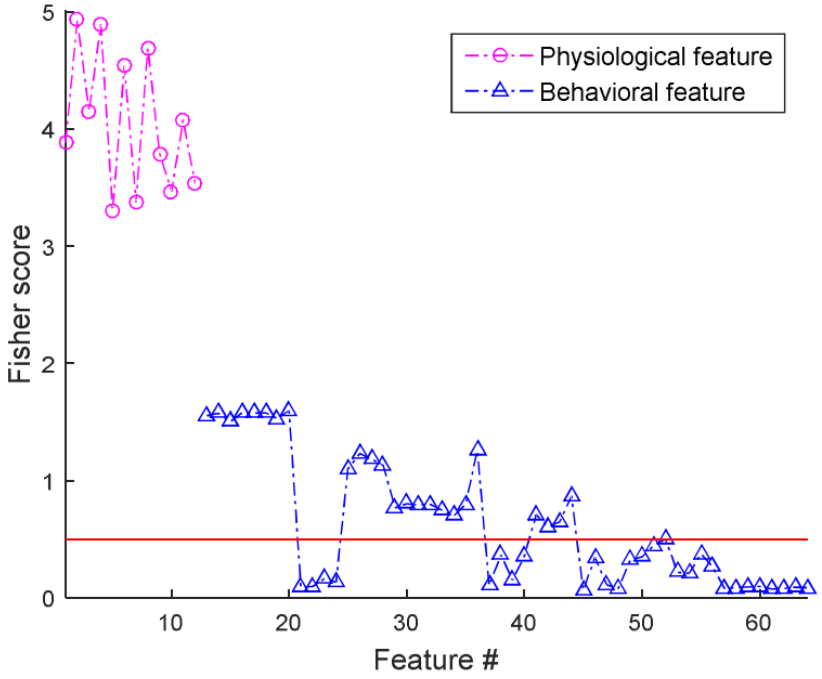


Fig. 4. The Fisher Score of the physiological and behavioral features. Features # from 1-12 are physiological; 13-64 are behavioral.

TABLE II. SELECTED FEATURES USING FISHER SCORE

Category	Feature Name	Selected #
Physiological	Point Distance	6
	Finger Width	3
	Length Difference	3
Behavioral	Length	8
	Time	4
	Velocity	4
	Tool	4
	Touch	4

One-Class Classifiers

- K-Nearest Neighbor
- Support Vector Machine

Evaluation

- Training:
  - 1 vs 160
  - 10% cross-validation
  - Random sample
- Evaluation metrics:
  - FAR, FRR, EER and ROC curve
- McNemar's test

Evaluation

- Effectiveness of TFST Gestures

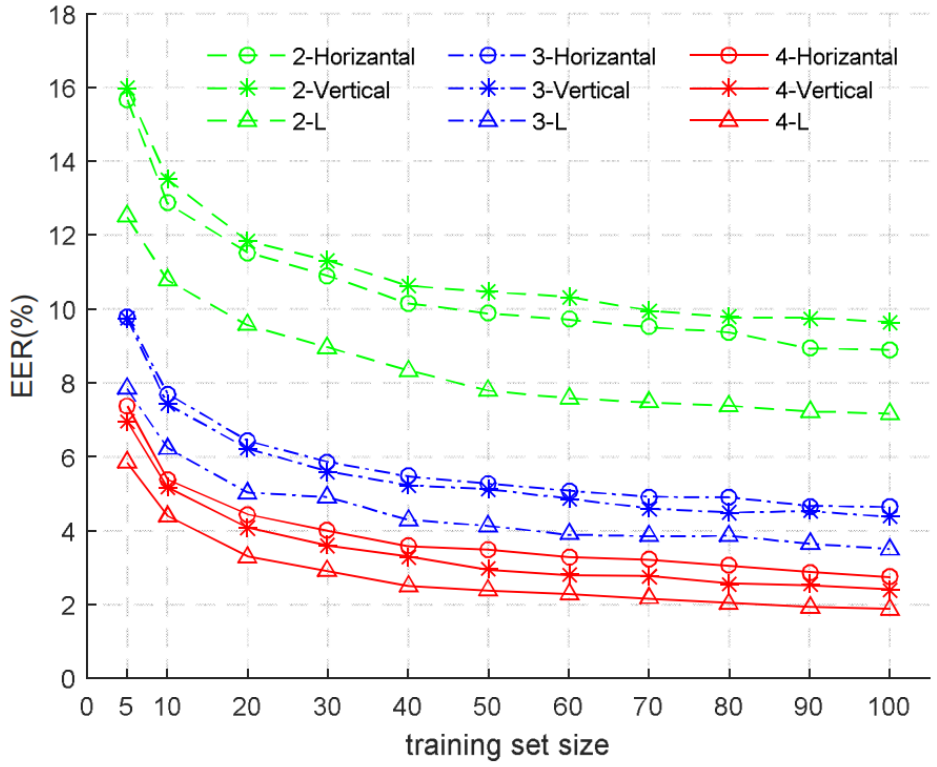


Fig. 5. EER curves for 9 types of gestures at varying training set sizes

Evaluation

- Effectiveness of different classifier

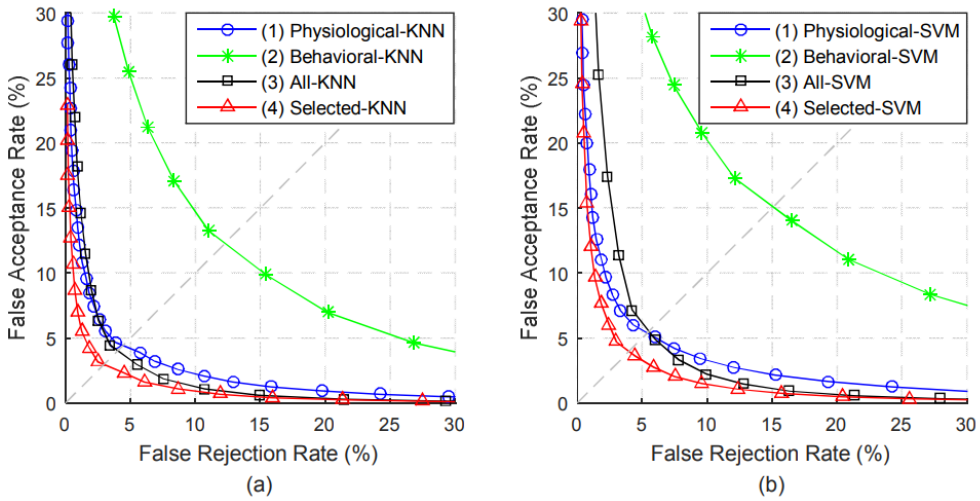


Fig. 6. ROC curves for 4 types of feature subsets using 2 types of classifiers: (a) K-Nearest Neighbor, (b) SVM

TABLE IV. COMPARISON OF TWO CLASSIFIERS USING MCNEMAR'S TEST

Better classifier	# of cases	Proportion (%)
KNN	126	87.5
SVM	6	4.17
Equivalent	12	8.33

Evaluation

- Effectiveness of training size

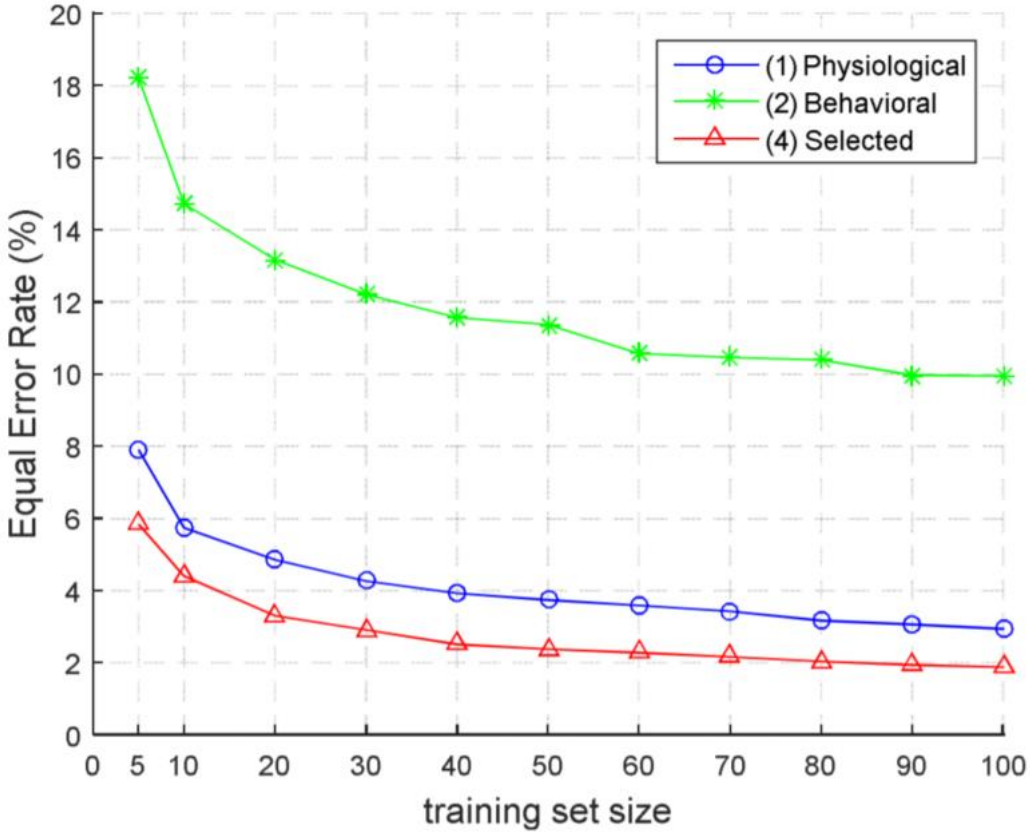
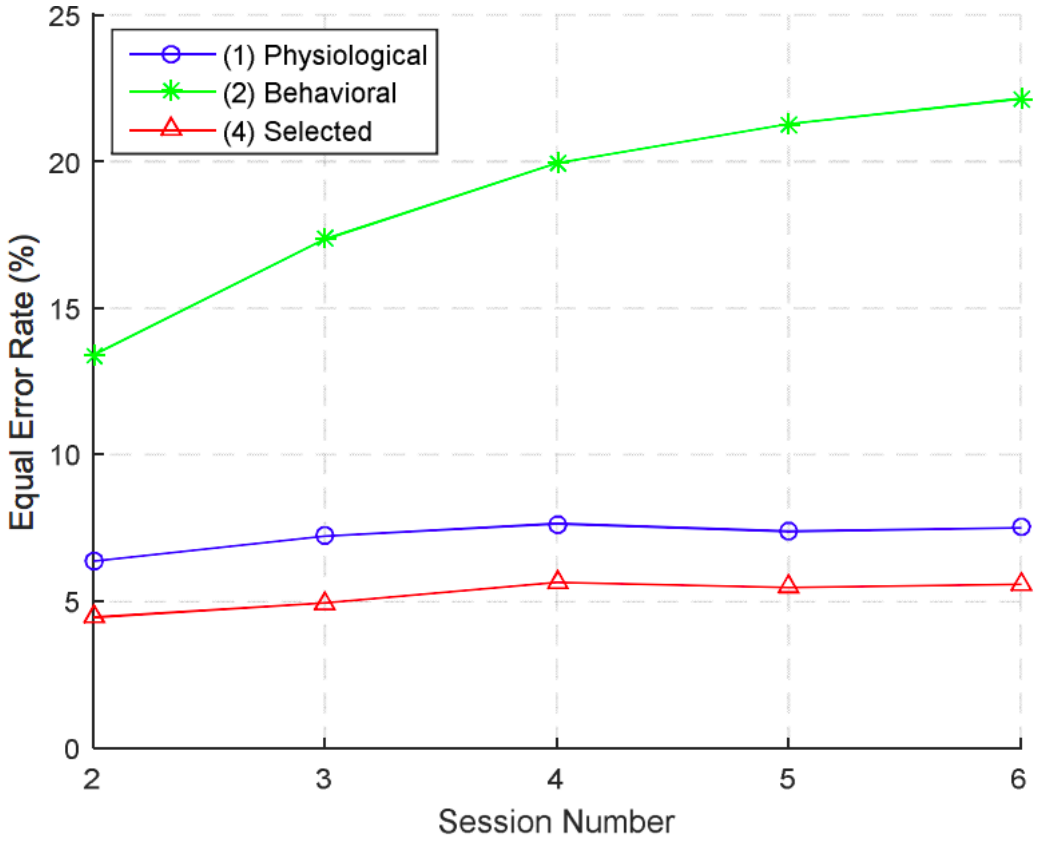


Fig. 7. EERs for 3 types of feature subsets at varying training set sizes

Evaluation

- Behavior variability



Evaluation

- Security Analysis: Zero-effort Attack
  - 1 vs 160
  - Similarity metric:

$$Sim_{ij} = 1 - \frac{\left|\left|v_i - v_j\right|\right|_1}{\left|\left|v_i + v_j\right|\right|_1}$$

TABLE VI. ZERO-EFFORT ATTACK AND HAND SIMILARITY (FARS ARE CALCULATED AT FRR=3%)

Similarity	# of pairs	Avg. FAR (Selected)	Avg. FAR (Physiological)
0	10296	4.41	5.60
0.95	2793	4.64	8.30
0.96	1309	4.82	9.01
0.97	404	4.92	9.12
0.98	59	5.04	9.33

Evaluation

- Security Analysis: Smudge and Shoulder Surfing Attack
  - Evaluation setup:
    - Another 20 students each attacks 10 victims
    - 5 victims with similar handshape, 5 victim with different handshape
    - Mimic 4-figer TFST

Evaluation

- Security Analysis: Smudge Attack

TABLE VII. EERS(%) OF SMUDGE ATTACK ON MODEL WITH 30-SAMPLE TRAINING

Type of Attack	Physiological	Behavioral	Selected
Zero-effort attack	4.06	12.10	3.02
Similar-handshape smudge attack	4.57	11.84	3.08
Dissimilar-handshape smudge attack	2.53	11.61	1.99

TABLE VIII. EERS(%) OF SMUDGE ATTACK ON MODEL WITH 100-SAMPLE TRAINING

Type of Attack	Physiological	Behavioral	Selected
Zero-effort attack	2.94	9.95	1.88
Similar-handshape smudge attack	3.16	9.13	2.00
Dissimilar-handshape smudge attack	1.69	8.66	0.96

Evaluation

- Security Analysis: Shoulder Surfing Attack

TABLE IX. EERS(%) OF SHOULDER SURFING AND COMBINED ATTACK ON MODEL WITH 30-SAMPLE TRAINING

Type of Attack	Physiological	Behavioral	Selected
Zero-effort	4.06	12.10	3.02
Shoulder surfing	4.92	12.88	3.31
Combined	5.20	13.34	3.67

TABLE X. EERS(%) OF SHOULDER SURFING AND COMBINED ATTACK ON MODEL WITH 100-SAMPLE TRAINING

Type of Attack	Physiological	Behavioral	Selected
Zero-effort	2.94	9.95	1.88
Shoulder surfing	3.61	10.18	2.06
Combined	4.18	10.44	2.27

Evaluation

- Security Analysis: Statistical attack

ALGORITHM 1: Generating forged features for statistical attack

```
Input: RealFeatures[ ]; //Population feature vectors
Input: NumberOfBins; //Number of bins for each feature
Output: ForgedFeatures[ ]; //Feature vectors used for attack
NumberOfFeatures = NumberOfRows(RealFeatures);
for i=1 to NumberOfFeatures
do
    BinnedFeatures[i] = Binning(RealFeatures[i], NumberOfBins);
    //Generate bins according to RealFeatures[i] and NumberOfBins
    KeyBin[i] = SortBinsByFrequency(BinnedFeatures[i]);
    //Sort bins in descending order of frequency
    LowerBound[i],UpperBound[i] = GetBound(KeyBin[i]);
    //get the bound of the first sorted bins
    AttackFeatures[i] = uniform(LowerBound[i],UpperBound[i]);
Return AttackFeatures[ ]
```

Evaluation

- Security Analysis: Statistical attack

TABLE XI. EERs (%) OF STATISTICAL ATTACKS ON MODEL WITH 30-SAMPLE TRAINING

Scenarios	Physiological	Behavioral	Selected
Zero-effort Attack	4.06	12.10	3.02
Statistical Attack	4.35	39.23	4.69

TABLE XII. EERs (%) OF STATISTICAL ATTACKS ON MODEL WITH 100-SAMPLE TRAINING

Scenarios	Physiological	Behavioral	Selected
Zero-effort Attack	2.94	9.95	1.88
Statistical Attack	2.17	32.67	2.43

Evaluation

- Usability Study

Fig. 10. Average ratings for the four usability questions

Questions ?