I Think, Therefore I Am

Usability and Security of Authentication Using Brainwaves

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TRUST Team for Research in Ubiquitous Secure Technology

Authentication via Brainwaves

- Thorpe et al. 2005 proposed concept of a *Pass-thoughts* system

- Feasibility established for multi-channel EEG signals
  - Marcel and Milan 2007 (n=9), Palaniappan 2008 (n=5), Ashby et al. 2011 (n=5), etc.

- Our study:
  - Single-channel EEG signals
  - Usability of brainwave authentication

Authentication via Brainwaves

- Single channel EEG offers significant cost and usability benefits
  - Example: embed in or integrate with consumer electronics, such as audio headsets, augmented reality eyewear
- Question 1: what about signal quality and authentication performance?
- Question 2: what about usability of the authentication process?

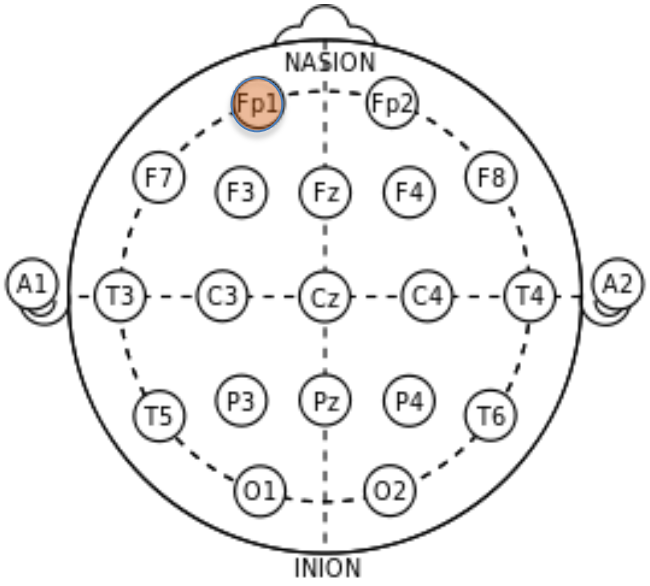
Key Findings

- Single-channel EEG signals exhibit patterns that are subject-specific
- Single-channel EEG authentication just as accurate as multi-channel EEG authentication
- Authentication performance not affected by type of mental task
- Recall rates consistently high for tasks requiring chosen secrets
- However, tasks score very differently in terms of user-perceived difficulty and enjoyability

Experiment

- Subjects (n=15) perform seven different mental tasks while their EEG signals (Fp1) are collected
- Complete questionnaire at the end of the session
- Return for a second session on a separate day to repeat the same tasks, and complete a second questionnaire

Neurosky Mindset headset



Frontal Polar 1 location

Seven Mental Tasks

Task	Description	Personal Secret	External Stimulus
breathing	Regular breathing with eyes closed		
finger	Simulated right index finger movement		
sport	Simulated muscle movement for chosen sport	✔	
song	Sing song or recite passage in the head	✔	
audio	Open eye upon hearing audio tone		✔
color	Count objects of chosen color on screen	✔	✔
pass-thought	Subject choose their own pass-thought	✔	

EEG Data

- Use power spectrum data for analysis
  - 5 trials/task * 7 tasks/session * 2 sessions/subject * 15 subjects = 1050 trial samples
- Pre-processing:
  - Temporal dimension: extract middle 5 seconds of each 10-second trial sample
  - Frequency dimension: separately extract **alpha wave** (8-12 Hz) and **beta wave** (12-30 Hz) ranges
  - Compression: one-dimensional column vector of median magnitudes of frequency components over entire time period
- Data analysis:
  - Cosine Similarity; Authentication; Classification

Cosine Similarity

$$\text{similarity}(u, v) = \frac{u \cdot v}{\|u\|\|v\|}$$

Subject	Self Similarity	Cross Similarity	Percent Difference
subject 0	0.7207	0.6653	7.99%
subject 1	0.7268	0.6745	7.46%
subject 2	0.7014	0.6602	6.05%
subject 3	0.7577	0.6397	16.89%
subject 4	0.7232	0.6617	8.88%
subject 5	0.6771	0.6702	1.02%
subject 6	0.7147	0.6264	13.17%
subject 7	0.7253	0.6817	6.20%
subject 8	0.7368	0.6828	7.61%
subject 9	0.6941	0.6435	7.57%
subject 10	0.7161	0.6847	4.48%
subject 11	0.7142	0.6816	4.67%
subject 12	0.711	0.6817	4.21%
subject 13	0.7028	0.6106	14.04%
subject 14	0.7099	0.6702	5.75%

Task	Self Similarity	Cross Similarity	Percent Difference
breathing	0.7304	0.6834	6.65%
finger	0.7282	0.6567	10.33%
sport	0.7144	0.676	5.52%
song	0.7013	0.6498	7.62%
audio	0.7283	0.6637	9.28%
color	0.6664	0.599	10.65%
pass	0.6931	0.632	9.22%

Self-similarity consistently higher than cross-similarity across all subjects and tasks, even for signals collected on different days

Authentication

- Threshold-based authentication protocol
- Minimize *Half Total Error Rate*: $HTER = (FAR + FRR)/2$
- Achieve 1.1% *HTER* with **customized task** and **customized threshold** for each subject
  - Can reduce task pool to just two (`breathing` and `audio`) and still maintain the same *HTER*

Common Threshold

Task	FAR	FRR	HTER
breathing	0.156	0.578	0.367
finger	0.044	0.733	0.389
sport	0.089	0.644	0.367
song	0.155	0.578	0.367
audio	0.244	0.400	0.322
color	0.244	0.622	0.433
pass	0.356	0.400	0.378

Customized Thresholds

Task	FAR	FRR	HTER
breathing	0.000	0.280	0.140
finger	0.067	0.120	0.093
sport	0.027	0.187	0.107
song	0.000	0.093	0.047
audio	0.027	0.147	0.087
color	0.120	0.440	0.280
pass	0.000	0.120	0.060
customized	0.000	0.022	0.011

Usability

- Difficulty AND enjoyability both factors in determining whether a subject would repeat a given task on a daily basis

Task	Was Difficult
breathing	0/15
finger	3/15
sport	7/15
song	4/15
audio	0/15
color	0/15
pass	7/15

Post-Session Questionnaire Data

Usability

- Difficulty AND enjoyability both factors in determining whether a subject would repeat a given task on a daily basis

Task	Was Difficult	Was Boring	Would Repeat
breathing	0/15	3/15	7/30
finger	3/15	8/15	0/30
sport	7/15	3/15	1/30
song	4/15	3/15	5/30
audio	0/15	4/15	4/30
color	0/15	3/15	9/30
pass	7/15	6/15	4/30

Post-Session Questionnaire Data

Recall

- Subjects had little difficulty recalling chosen secrets in follow-up session
  - For `Color` task, choose from fixed menu: {`red`, `green`, `blue`, `yellow`}

Task	Recall Rate
song	15/15
sport	15/15
color	14/15
pass	15/15

Future Directions

- Scale beyond workgroup-sized populations
- Optimal number and selection of tasks
  - User enrollment; user choice; authentication performance
- Classification performance
- Robustness, e.g., against impersonation attacks

Conclusion

- First study of brainwave authentication using single-channel EEG signal
- First experimental study of usability design of brainwave-based authentication
- Brainwave authentication may be less exotic than you think:
  - High accuracy with low-cost non-intrusive sensors
  - Easy to embed sensors in consumer electronics and wearable computing devices
- Brainwave authentication systems can be designed to allow users to choose tasks that they find easy and enjoyable

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