Eye Movement Biometrics: Its Future and Applications

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Eye Tracking Technology

(x,y,t)
Working Principle

- **Hardware**
  - IR light
  - Image sensor

- **Eye Features**
  - Corneal reflection
  - Pupil
Eye Tracker vs. Iris Scanner

Eye Tracker
Eye tribe eye tracker

Iris Scanner
CMITech DMX-10 Iris Scanner
Important Eye Tracker Characteristics

- Sampling rate 15-20Hz
- Spatial accuracy 0.5-2°
- Spatial precision >0.02°
Goals:
- Higher security
- Better accuracy
HVS: eye movement types

- **Eye-fixations**
  - high acuity vision
    - eye is stable in regard to the object of interest
    - eye speed < 5°/sec (or < 30°/sec )

- **Saccades**
  - no vision – fastest movement in human
    - move eyes between eye-fixations very rapidly
    - eye speed up to 700°/sec
He had forty-two boxes, all carefully packed,
With his name painted clearly on each:
But, since he omitted to mention the fact,
They were all left behind on the beach.

The loss of his clothes hardly mattered, because
He had seven coats on when he came,
With three pairs of boots—but the worst of it was,
He had wholly forgotten his name.

He would answer to "Hi!" or to any loud cry,
Such as "Pry me!" or "Fritter my wig!"
To "What-you-may-call-um!" or "What-was-his-name?"
But especially "Thing-um-a-jig!"

While, for those who preferred a more forcible word,
He had different names from these:
His intimate friends called him "Candle-ends,"
And his enemies "Toasted-cheese."

"His form in ungainly—his intellect small—"
(So the Bellman would often remark)
"But his courage is perfect! And that, after all,
Is the thing that one needs with a Snark."

He would joke with hyenas, returning their stare
With an impudent wag of the head:
And he once went a walk, paw-in-paw, with a bear,
"Just to keep up its spirits," he said.
Eye Movement Control

- Brain
- Oculomotor plant
  - extraocular muscles + eye globe with surrounding tissues

WHERE

neuronal control signal

HOW
Oculomotor Plant Characteristics

- Passive elasticity
- Neuronal control signal
- Active state tension
  - Length tension relationship
  - Force velocity relationship
  - Series elasticity
- Eye globe inertia
- Viscous properties of the eye globe
Muscle Immobile State - Forces

Muscle Lateral Rectus

\( N_{LR} \) - muscle innervation through motoneuronal firing by Central Nervous System.

\( F_{LR} \) – active force is generated to contract the muscle

\( K_{LT}\theta_{LT_{LR}} \) – additional contractile force is added through spring-like length-tension component

\( K_{SE}\theta_{SE_{LR}} \) – spring-like series-elasticity component resists contractile force
**Agonist – Forces**


\[ K_{SE}(\theta_{SE_{LR}} + \Delta \theta_{SE_{LR}}) \]

\[ K_{LT}(\theta_{LT_{LR}} + \Delta \theta_{LT_{LR}}) \]

\[ T_{LR} \]

\[ F_{LR} \]

\[ N_{LR} \]

\[ B_{AG} \cdot V \rightarrow \text{damping (force velocity component) resists contraction when a muscle shortens} \]

\[ \frac{K_{SE}K_{LT}}{K_{SE} + K_{LT}} + \frac{K_{SE}\hat{F}_{LR}}{K_{SE} + K_{LT}} \cdot \hat{B}_{AG} \]
2D Oculomotor Plant Model

- 12 Differential Equations
- 36 OP Characteristics
- The model simulates saccades
**CEM Characteristics**

- Fixation related
  - Number of fixations
  - Fixation duration

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He had forty-two boxes, all carefully packed,  
With his name painted clearly on each:  
But, since he omitted to mention the fact,  
They were all left behind on the beach.

The loss of his clothes hardly mattered, because  
He had seven coats on when he came.  
With three pairs of shoes—but the worst of it was,  
He had wholly forgotten his name.

He would answer to "Hi!" or to any loud cry,  
Such as "Freemal!" or "Futter my wig!"  
To "What you make a fear?" or "Who was his name!"  
But especially "Firing-up a rig!"
CEM Characteristics

- Saccade related
  - Saccade amplitude

He had forty-two boxes, all carefully packed,
With his name painted clearly on each:
But, since he or I tried to mention the fact,
They were all left behind on the beach.

The loss of his clothes hardly mattered, because
He had seven coats on when we came.
With three pairs of boots— but the worst of it was,
He had wholly forgotten his name.

He would answer to "Hi!" or to any loud cry,
Such as "Fire me!" or "Patter my wig!"
To "What you may call me," or "What was his name?"
But especially " Thing-um-bob- jig!"
CEM Characteristics

- Scanpath related
  - Length
  - Inflections
CEM Characteristics

- Scanpath related
  - Area
CEM Characteristics

- Scanpath related
  - Fixation distances
320 subjects
- 170 male/150 female, ages 18-46

4 types of visual stimuli

High-grade commercial eye-tracker ($30,000)
- EyeLink 1000, Monocular mode, captured eye: left
- Sampling rate: 1000 Hz
- Spatial accuracy: ~0.5°
- Spatial resolution: ~0.02° RMS

Time interval
- ~20 minute between samples
Current Best Results

- **Current Best Results** *
  - Rank-1 IR: 88.6%
  - EER: 5.8%
  - GAR at 0.1% FAR: 76.7%

- **Past Results** (CEM-B – 2.5 years ago)
  - Rank-1 IR: 49.5%
  - EER: 15.4%

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## Bio Eye 2015 Competition: Results

<table>
<thead>
<tr>
<th>Rank</th>
<th>Participant</th>
<th>RAN_Short</th>
<th>RAN_Long</th>
<th>TEX_Short</th>
<th>TEX_Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Baseline*</td>
<td>34.0</td>
<td>40.5</td>
<td>58.2</td>
<td>48.6</td>
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<tr>
<td>1</td>
<td>A. George and Prof. A. Routray Indian Inst. of Tech. Kharagpur</td>
<td>98.7</td>
<td>89.2</td>
<td>98.0</td>
<td>94.6</td>
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<td>2</td>
<td>N. Abe Fujitsu Laboratories Ltd.</td>
<td>88.9</td>
<td>59.5</td>
<td>91.5</td>
<td>67.6</td>
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<td>3</td>
<td>P. Kasprowski Silesian Un. of Technology</td>
<td>75.8</td>
<td>54.1</td>
<td>73.2</td>
<td>45.9</td>
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</table>

Limitations: Today’s Technology

- Requires high quality signal
  - Calibration
  - Cooperative subject
- Minimum data acquisition sample
  - 10-100 sec.
Applications of Eye Movement Biometrics
Wearables: Google Glass

Google Faculty Research Award, *Eye Movement-Driven Biometrics and Interaction on Google Glass*, award #2014_R1_308
Google Glass: Colored Lens
Google Glass: Patterned Contact Lens Demo
Google Glass: Example of Captured Signal

eye positional samples (count) vs. eye position (deg)
### Google Glass: Mean Absolute Error

<table>
<thead>
<tr>
<th>Task</th>
<th>Horizontal MAE (°)</th>
<th>Vertical MAE (°)</th>
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</thead>
<tbody>
<tr>
<td>Horizontal saccades</td>
<td>1.90</td>
<td>1.54</td>
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<tr>
<td>Random saccades</td>
<td>1.43</td>
<td>1.27</td>
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<tr>
<td>Text reading</td>
<td>0.98</td>
<td>1.12</td>
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</tbody>
</table>

Liveness Detection: Iris Print Attacks

- 200 recorded subjects
- 1 “professional” attacker impersonating subjects
- Average Classification Rate (ACR) 96.5%
- ACR of ~90% with sampling frequency of 15Hz
Liveness Detection: Attack of Mechanical Replicas

- 32 recorded subjects
- 3 mathematical models
- Correct Classification Rate (CR) 88-100%

Detection of “Health States”
Concussion Related Metrics
Concussion Detection: Results

- 32 Subjects
- 30 Healthy
- 2 mTBI (concussed)
- 8 recordings per subject
- Detection accuracy rate 92%

Conclusions

- Eye movement-driven biometric techniques provide
  - Previously unexplored sources of information about a human identity
  - Strong liveness detection capabilities
  - “Health state” detection capabilities
  - Can be run on inexpensive web-cameras and potentially on the existing iris recognition devices
Sponsors

NSF

Google

NIST

SMI

SensoMotoric Instruments