Oculomotor Plant Biometrics: Person-Specific Features in Eye Movements

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Abstract

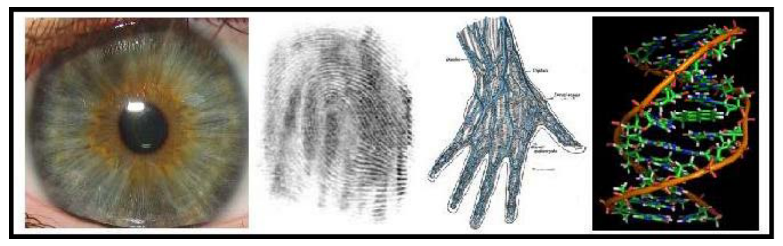
This study presents a new biometric approach that involves an estimation of the unique oculomotor plant (OP) or eye globe muscle parameters from an eye movement trace. It includes both behavioral and physiological human attributes, is difficult to counterfeit, non-intrusive, and could easily be incorporated into existing biometric systems to provide an extra layer of security.

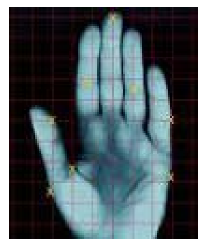
Background

Biometrics: Refers to methods for uniquely recognizing humans based upon one or more intrinsic physical or behavioral traits. There are two major categories of biometric identification: Physiological and Behavioral

Physiological

Related to the shape of the human body.

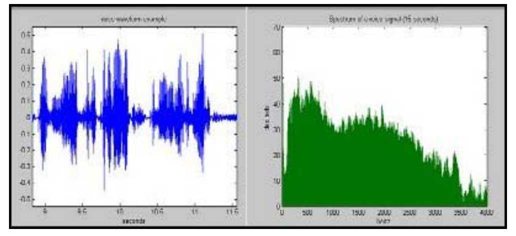


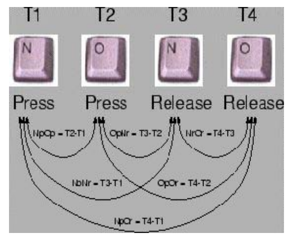


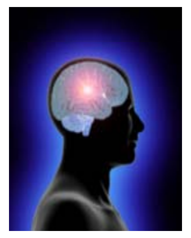
- Hand and palm prints and geometry
- Fingerprints
- Vascular (vein) patterns
- Face/Iris
- Voice/ Speech
- Odor/ Scent
- DNA

Behavioral

Related to the behavior of a person.







- Brain waves
- Voice/speech
- Typing rhythm, handwriting, and signature
- Gait analysis (human locomotion)

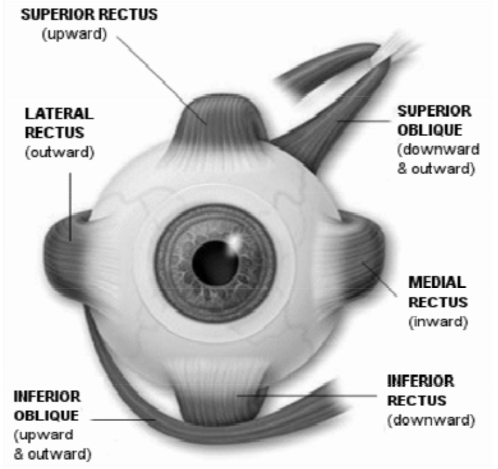
Oculomotor Plant Biometrics

Most popular biometric identification methods such as fingerprint verification or iris recognition are based on physiological properties of the human body.

However, physiological properties are vulnerable to forging and may be used to identify an unconscious or even a dead person.

Eye Movements combine both physiological (muscle) and behavioral (brain) aspects.

Eye movement based identification uses information mostly produced by the brain, and so far impossible to imitate.

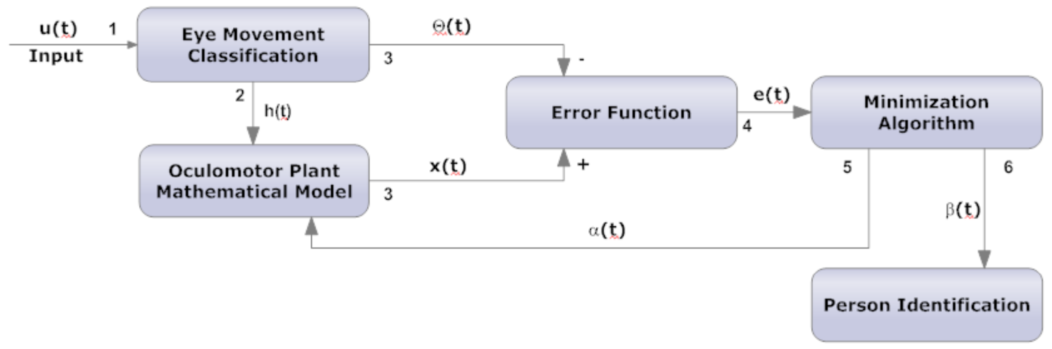


Eye Movements:

1. Saccades
2. Fixations
3. Smooth Pursuits
4. Optokinetic reflex
5. Vestibule-ocular reflex
6. Vergence

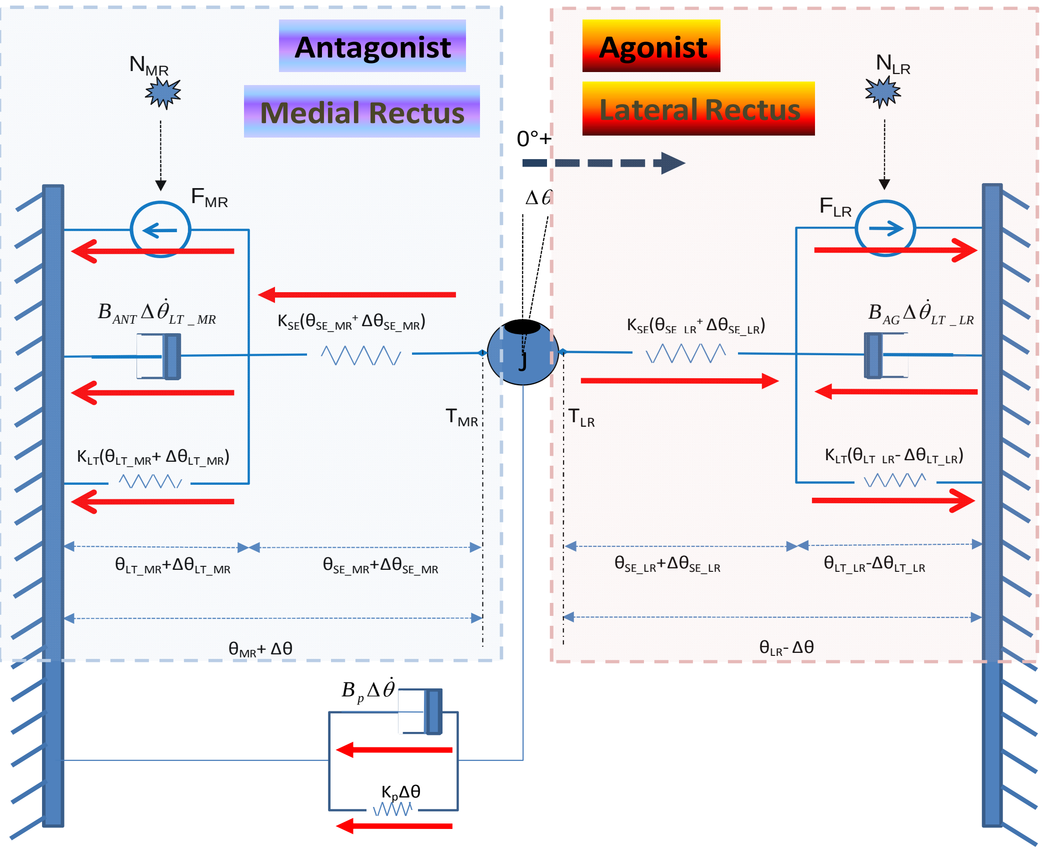
Eye Movement Classification Algorithms: Velocity Threshold (I-VT), Hidden Markov Model (I-HMM), Kalman Filter (I-KF), Minimum Spanning Tree (I-MST), Dispersion Threshold (I-DT).

Oculomotor Plant Mathematical Model (OPMM)



Eye Movement Classification: The Velocity-Threshold (I-VT) algorithm in the Eye Movement Classification module is employed to split an eye movement recording into fixations and saccades. A velocity threshold of 55º/s is employed to separate fixations from saccades

Oculomotor Plant Mathematical Model: The OPMM presented in this subsection represents the anatomy of the right eye and presents mathematical equations for rightward saccades. The rightward saccades are performed by the lateral rectus (the muscle that is closer to the ear) as the agonist and by the medial rectus (the muscle that is closer to the nose) as the antagonist. The agonist muscle pulls the eye globe in the required direction and the antagonist muscle resists the pull.



Error Function: Saccade trajectories generated by the Eye Movement Classification module and the OPMM module are supplied to the Error Function module, where the error e(t) between those two signals is computed. We compute the Root Mean Squared Error (RMSE) between the detected x(t) and the simulated Θ(t) OPMM eye position signal.

Minimization Algorithm: One of the ways to derive more accurate values for the OPMM parameters is to employ an optimization algorithm that selects new values for the OPMM parameters with an objective of minimizing the error e(t). We employed two optimization algorithms to determine optimized values for the OPMM parameter vectors (LR_P, LR_S, K_{LT},K_{SE}, B_{AG}, K_P, J) with an objective of minimizing the error e(t).

First, the Trust-Region (TR) algorithm that uses the interior-reflective Newton method was applied. The TR algorithm is an optimization method that looks for a better value of the input parameter given its initial value.

Additionally, the Nelder-Mead (NM) simplex algorithm was applied. This algorithm employs a simplex of n+1 points for a vector y with n dimensions.

Person Identification: . In order to perform the classification, we evaluated two different statistical algorithms, the K-nearest neighbor (KNN) algorithm, and C4.5. KNN is a very simple instance-based learning algorithm, and C4.5 is a freely-available classifier that builds a decision tree based on the concept of information entropy.

Experimental Methodology

Apparatus: The experiments were conducted with a Tobii x120 eye tracker.

Eye Movement Invocation Task: The stimulus was presented as a 'jumping point' with vertical coordinate fixed to the middle of the screen.

Participants: The test data consisted of 68 student volunteers ages 18-25 with an average age of 21.2 and standard deviation of 3.2, 24 males and 44 females, with normal or corrected-to-normal vision. Only 41 subject records passed the selection criteria, resulting in mean accuracy of 1.25º (SD=0.77˚) and a mean invalid data percentage of 12.43% (SD=17.22%). Only saccades with amplitudes of 17-22º were employed for biometric identification.

Performance evaluation metrics

False Acceptance Rate (FAR) – The ratio of the number of imposter samples classified as authentic to the total number of all the imposter samples.

False Rejection Rate (FRR) – The ratio of the number of authentic samples classified as imposters to the number of all the authentic samples.

Results

KNN										
Optimization	Metric	LR_P	LR_S	K_{LT}	K_{SE}	B_P	B_{AG}	K_P	J	D
TR-S1	FAR	26.3%	26.3%	5.3%	26.3%	21.1%	26.3%	36.8%	42.1%	26.3%
TR-S1	FRR	66.6%	64.5%	56.6%	66.6%	66.6%	70.0%	73.3%	76.6%	70%
TR-S2	FAR	31.6%	36.8%	21.1%	26.3%	36.9%	31.6%	31.6%	21.1%	26.6%
TR-S3	FRR	73.3%	76.7%	70%	63.3%	80%	73.3%	76.7%	70%	68.9%
NM-S1	FAR	26.3%	36.8%	26.3%	42.1%	26.3%	26.3%	15.8%	47.4%	15.9%
NM-S1	FRR	68.8%	78.1%	71.9%	81.3%	71.9%	68.8%	62.5%	81.3%	62.5%
NM-S2	FAR	31.6%	31.6%	26.3%	42.1%	26.3%	21.1%	36.8%	31.6%	36.9%
NM-S2	FRR	71.9%	71.9%	68.8%	81.3%	68.8%	68.8%	75%	75%	78.1%

C4.5		
Optimization	Metric	D
TR-S1	FAR	87.2%
TR-S1	FRR	4.25%
TR-S2	FAR	79.5%
TR-S3	FRR	4.1%
NM-S1	FAR	94.1%
NM-S1	FRR	2%
NM-S2	FAR	80%
NM-S2	FRR	0%

We conducted the classification with both the KNN (top table) and C4.5 algorithms on each of the OPMM parameters, and determined that the best results were obtained with KNN utilizing the TR algorithm with optimization strategy 1 for the length tension coefficient. These results improve on previous work in the field by Kasprowski (Kasprowski 2004).

Discussion, Conclusion and Further Work

We have introduced a novel method of biometric identification based on the utilization of Oculomotor Plant Mathematical Model parameters from horizontal positive saccadic eye movements.

Via our tests, we demonstrated the potential to distinguish authorized users from imposters with this technique.

This new method could also be easily combined with existing biometric identification systems that incorporate digital cameras to scan the face or iris, to provide an additional layer of security.

However, further testing with larger subject pools and different statistical classification algorithms is needed to improve on the accuracy rates of our method.

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Acknowledgments

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