Biometric Identification System using Eye Movement Analysis

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Abstract: This paper formalizes an algorithm that provides fast and robust analysis of eye-movement data. Paper presents the biometric identification system by using extracted features based on fixation and saccade points. Velocity threshold based fixation identification algorithm is employed for processing the raw scan path signals in eye movement matrices. I-VT is a velocity-based method that separates fixation and saccade points based on their point-to-point velocities. A neural network model is deployed for classification over data retrieved from scan-path signals. So we can say paper demonstrates a novel biometric identification system by an objective evaluation of various eye movement-based biometric features and their ability to accurately and precisely distinguish unique individuals.

Keywords: Counterfeit Resistant, Fixation Identification, Saccade Identification, Fixation Count, Average Fixation Duration, Average Vectorial Saccade Amplitude, Average Horizontal Saccade Amplitude, Average Vertical Saccade Amplitude, Scanpath Length.

I. INTRODUCTION

Biometrics system identifying an individual by his or her physiological or behavioral characteristics has capability to determine between authorized user and pretender. So Biometrics has been broadly utilized as a part of criminology applications, for example, criminal recognizable proof and jail security. It additionally has a solid potential to be generally received in regular citizen applications, for example, e-Banking, e-Commerce, and access control. There are various biometric technologies available such as fingerprint, iris, face, retinal, palm prints, hand geometry, voice, and signature etc. which are being used for biometric recognition in recent past. However, some of these traits are easier to reproduce and causes a gap in identification accuracy. Therefore it is necessary that biometric traits should not be easy to reproduce. Eye movements characteristics depend on the brain activity and extra-ocular muscles properties that make it highly counterfeit resistant. Therefore, it is not possible to accurately replicate the eye movement of any individual. The researches in eye movement as biometric trait is at very initial stage and require more attention to work with advance Computational intelligence techniques besides the conventional statistical techniques used in [1], [2], [6] for recognition. In this paper, we use a neural network model in training and testing module. For feature extraction from the raw scan path signals, we adopt velocity threshold (I-VT) identification algorithms [3] for fixations and saccades identification. Saccades occur when eye rotates quickly between fixations and fixation occurs when eye is held in relatively stable position on an object [2]. Schematic diagram of the proposed methodology is presented in fig. 1 which involves three basic processes:

fixation identification from raw eye motion signals [4]; derivation of eye movement matrices from fixations / saccades groups and finally training and testing which employs neural network model.

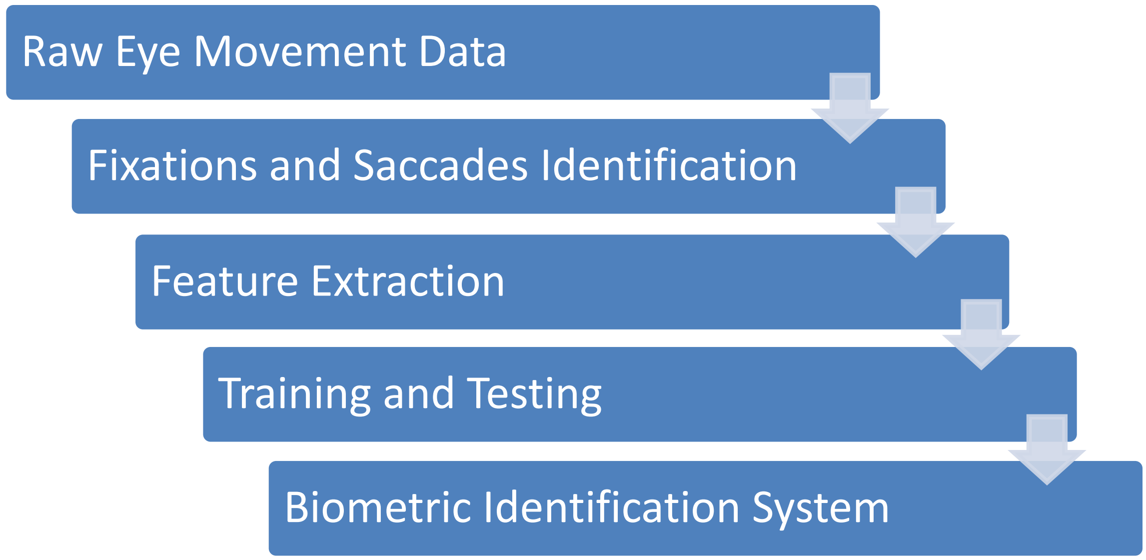

Figure1. Schematic diagram of proposed methodology

On the other hand, neural network (NN) is used for biometric identification. Neural network is a mathematical model or computational model based on biological neural network. It consists of an interconnected group id artificial network and processes information using a connectionist approach to computation. The neural network may contain, input layer, output layer, and one or more several hidden layers. The neural network works by adjusting the weight values during training in order to reduce the error between the actual and desire output pattern.

II. PROPOSED METHODOLOGY

The raw Eye Movement Data produced during various recordings is supplied to the Eye Movement Classification module which identifies, filters, and merges the data points that describe the unique fixations/saccades present in each. Fixation and saccade groups are merged, identifying fixation-specific and saccade-specific features. The extracted features are supplied to the training and testing module and training & testing is done by neural network.

A. Fixations and Saccades Identification:

I-VT is a velocity-based method that separates fixation and saccade points based on their point-to-point velocities. The velocity profiles of saccadic eye movements show essentially two distributions of velocities: low velocities for fixations, and high velocities for saccades.

I-VT (protocol, velocity threshold):

- Calculate point-to-point velocities for each point in the protocol, each velocity (vel) is computed as the distance between the current point and the next (or previous) point.
  $vel = \sqrt{((x2 - x1)^2 + (y2 - y1)^2)}$ (1)
- Calculate the threshold (th), th = $\sum$ vel / Total no of samples (s)
- If(vel<th)

  Label each point as a fixation point.

  Else

  Saccade point.
- Collapse consecutive fixation points into fixation groups, separate saccade points.
- Translates each fixation group to a <x,y,t,d> fixation tuple using the centroid1 of the points as x and y, the time of the first point as t, and the duration of the points as d. Return fixations.

B. Feature Extraction:

After getting fixations saccades, we select 6 eye movement metrics as fixation count (FC), average fixation duration (AFD), average horizontal, vertical and vectorial saccade amplitude (AHSA, AVRSA and AVCSA) and Scanpath Length [2] which are defined as following:

- **Fixation Count**: Number of detected fixations.
- **Average Fixation Duration**: It indicates the amount of time a subject spends interpreting an object [8]. It is measured as sum of fixation durations over fixation count.
  Let FC= Number of fixations, d is the fixation duration
  And S=Number of saccades then,

$$AFD = \frac{\sum_{i=1}^{FC} d_i}{FC} \quad (2)$$

- **Average Vectorial Saccade Amplitude**: There is a noted tendency for saccades to maintain similar amplitudes during reading [7]. Average saccade amplitude is considered as biometric feature under assumption that differences in amplitude may be apparent between subjects. It is measured as sum of vectorial saccade amplitudes over the total number of saccades as:

$$AVCSA = \frac{\sum_{i=1}^{S} \sqrt{x_i^2 + y_i^2}}{S} \quad (3)$$

- **Average Horizontal Saccade Amplitude**: Average amplitude of the horizontal component of saccadic movement.
- **Average Vertical Saccade Amplitude**: Average amplitude of the vertical component of saccadic movement.
- **Scanpath Length:** Scanpath length is indicative of the efficiency of visual search [8]. Scanpath length was measured as the sum of absolute distances between the vectorial centroid of fixation points, where the vectorial

centroid was defined as the Euclidean norm of the horizontal and vertical centroid positions, according to the equation:

$$Scanpath\ Length = \sum_{i=2}^{n} \left| \sqrt{x_i^2 + y_i^2} - \sqrt{x_{i-1}^2 + y_{i-1}^2} \right| \qquad (4)$$

C. Training And Testing:

In this dissertation, neural network (NN) is used for biometric identification. Neural network is a mathematical model or computational model based on biological neural network. It consists of an interconnected group id artificial network and processes information using a connectionist approach to computation. Back propagation neural network is a systematic method for training multi-layer neural network. The BP neural network may contain, input layer, output layer, and one or more several hidden layers. The neural network works by adjusting the weight values during training in order to reduce the error between the actual and desire output pattern.

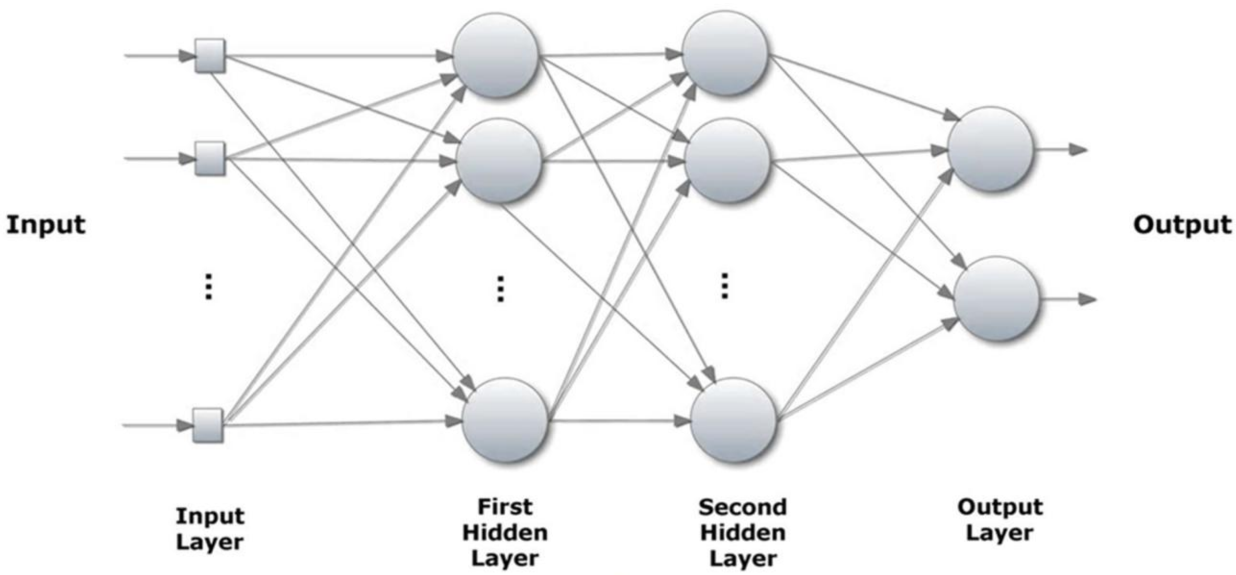

Figure2. Multi-layer Neural Network

Firstly, the input and target samples of the neural network are obtained. After that, the matrix is converted into a 6×1 column vector that is treated as the input of the neural network (Fig. 2). The input layer of the neural network has 6 neurons. Learning procedure assumes that each input vector is paired with a target vector representing the desired output; together they are called a learning pair. For the output layer, if 32 learning pairs are required, the output layer neurons are 32. Output is restored in a 32×1 column vector. For the number of hidden layer neurons, we refer to the empirical formula Eq. (5). We set the number of hidden layer neurons to 40.

The k-th output of neural network is determined by the formula.

$$P_k = f\left(\sum_{i=1}^{h2} v_{it} \cdot f\left(\sum_{k=1}^{h1} U_{kt} \cdot f\left(\sum_{j=1}^{m} W_{jt} X_j\right)\right)\right) \qquad (5)$$

In Eq.(5), $X_1, X_2, \ldots, X_j$ are grayscale values of input array that characterizes the Features information, $P_1, P_{2,\ldots\ldots,} P_k$ are output patterns that characterize the eye movements. Where V_{it} weights between the hidden layers and output layers of network, U_{kt} are weights between the hidden layers, W_{jt} are weights between the input and hidden layers, f is the activation function that is used in neurons. m is the number of input signals, $h1$ and $h2$ are the number of neurons in hidden layers, n is the number of output neurons ($k=1,..,n$). The back propagation learning algorithm is applied for training of neural network [5]. The trained network is then used for eye movements testing. For testing, feature vectors of unknown eye movement metrics are fed into the neural network. A pattern is identified by corresponding member of cluster for which maximum value of threshold is obtained. Thus, eye movement metrics are classified by neural network.

III. EXPERIMENTAL SETUP & SOFTWARE

We have used EMBD V1.0 [2] in which raw scan path signals are provided for 32 subjects (26 males / 6 females), ages 18 – 40 with an average age of 23 (SD = 5.4). 29 of the subjects performed 4 recordings each, and 3 of the subjects performed 2 recordings each. Each recording contain nearly 60,000 raw scan-path signals. For 29 subjects, we select 2 recordings for training and rest 2 for testing; while for 3 subjects, single recording is used for training and rest single is for testing.

We have used MATLAB software, and experiments are performed on Intel Core 2 Duo CPU, i.e. 2.00GHz PC with 2 GB RAM.

IV. RESULTS AND ANALYSIS

I-VT is straightforward to implement, runs very efficiently, and can easily run in real time. Fixation identification takes as input an eye-movement protocol comprising a sequence of <x,y> data points. It then transforms the protocol to a sequence of <x,y,t,d> fixation tuples, where x and y indicate the fixation location, t indicates the onset time at which the fixation occurred, and d indicates the duration of the fixation. Finally, I-VT translates each fixation group to a <x,y,t,d> fixation vector.

TABLE1. EXAMPLE OF A FIXATION GROUP

Time stamp	X degree	Y degree	Velocity
8.0000	17.4361	11.1618	0.0080
9.0000	17.4361	11.1699	0.0028
10.0000	17.4342	11.1719	0.0055
11.0000	17.4380	11.1679	0.0038
12.0000	17.4342	11.1679	0.0083

TABLE2. EXAMPLE OF FIXATION VECTOR

x	y	t	d
-1.8401	-1.6321	0	23
-1.8134	-1.594	26	56
-1.8095	-1.6259	85	17
-1.7919	-1.5176	104	2
-1.7922	-1.6031	108	8

The performance of the system is measured in terms of testing accuracy which is defined as:

Testing accuracy = 100 × (number of correct matches/total number of samples in test set) (6)

TABLE IV COMPARATIVE ANALYSIS OF BIOMETRIC IDENTIFICATION USING I-VT:

Dataset	**Testset**	**Threshold**	**Accuracy (%)**
32	64	0.1	54.6
32	64	0.2	56.7
32	64	0.4	60
32	64	0.7	63.8
32	64	0.9	67

We observed that best results are obtained at different values of threshold. In experiments it is also observed that best accuracy could be obtained when threshold value is increased. A maximum 67% accuracy has been obtained by combining I-VT with NN that demonstrates the Capability of eye movement scan-path signals as biometric features.

The False Reject Rate (FRR) measures the probability that an individual who has enrolled into the system is not identified by the system. It is also known as Type-I error.

FRR can be calculated as:

$$FRR(n) = \frac{Number\ of\ rejected\ verification\ attempts\ for\ a\ qualified\ individual\ n}{Totalnumber\ of\ verification\ attemps\ for\ that\ qualified\ individual\ n}$$

And FRR= $1/N \sum_{n=1}^{N} FRR(n)$ (7)

The False Acceptance Rate (FAR) measures the probability that an individual who may have or have not enrolled into the system is identified as another individual. It is also known as a Type-II error.

FAR can be calculated as:

$$FAR(n) = \frac{Number\ of\ successful\ imposter\ attempts\ for\ a\ qualified\ individual\ n}{Totalnumber\ of\ imposter\ attemps\ for\ that\ qualified\ individual\ n}$$

And FAR= $1/N \sum_{n=1}^{N} FAR(n)$ (8)

Where N is the total number of enrollments.

From experimental results it is found that the biometric identification using I-VT has a FRR of 39.2 % and FAR of 38.5 %. Since FAR and FRR are nearly equal, therefore equal error rate(EER) is also 39% for I-VT.

V. CONCLUSION

This paper has presented the potential applicability of the eye movement scan path signals for biometric analysis. We have presented neural network based eye movement analysis which allows for the combination of multiple metrics to produce more stable/accurate identification. The algorithm performed four major steps: The first one is analysis of raw eye movement data, The second one is fixation and saccade identification using I-VT and I-

DT algorithm, The third one is feature extraction by using fixation and saccade points and The last one is biometric identification by training and testing of features using neural network. And we observed that I-VT is straight forward to implement, runs very efficiently, can easily run in real time and provide high accuracy.

In the current paper, we have applied simple velocity threshold and dispersion threshold algorithm. It is likely that future research will investigate alternative classification algorithms/thresholds to identify more effective solutions. In future work, one can employ learning and visual search characteristics of human brain and can add more eye movement metrics for identification purposes.

ACKNOWLEDGEMENT

I would like to thank my mentor Dr. Vivek Srivastava for introducing me to this exciting area of Biometrics. Authors would also like to thanks to Dr Oleg Komogrtsev and Dr Corey Holland for providing EMDB V1.0 dataset and valuable suggestion in pre-processing the dataset.

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