A Video-Based Spatio-temporal Biometric Template Representation of the Spontaneous Pupillary Oscillations: A Pilot Experiment

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Abstract. In this paper, we introduced a new video-based spatio-temporal identification system and we also presented our initial identity authentication results based on the spontaneous pupillary oscillation features. We demonstrated that this biometric trait has the capability to provide enough discriminative information to authenticate the identity of a subject. We described the methodology to compute a spatio-temporal biometric template recording the pupil area changes from a video sequence acquired at constant light conditions. To our knowledge, no attempts were made in order to distinguish individuals based on the spatio-temporal representations computed from the normal dilation/contraction condition of the pupil. In preliminary experiments, for the privately collected database, we observe that Equal Error occurs at a threshold of 5.812 and the error is roughly 0.4356%.

Keywords: Spatio-temporal biometric template, spontaneous pupillary oscillations, hippus.

1 Introduction

In humans, the iris around the pupil is one of the few autonomic physiological effectors that are immediately accessible to the eye. Eye-based biometric systems have some modalities: iris, retina, sclera veins, etc. [1, 6, 7, 8, 12, 16, 17, 18, 19,21], which sometimes are combined or fused, for example, using iris/retina features. This work introduced a spatio-temporal representation of the pupil dynamic features extracted from a video sequence acquired at constant external light conditions. This new approach employs the spontaneous pupillary oscillations as a liveness indicator by recording the pupil area fluctuations from the video record (Fig. 1). The spatio-temporal biometric template that has been proposed to extract efficiently the uniquely identifiable local dynamic features of the pupil is described in this work.

Since the eye-based biometric systems have unique features in their templates, so far in the existing literature there is not any identification method that completely relies on the pupil itself. This may be perhaps due to the difficulty in extracting and representing the “exact” features of the pupil.

The goal of this study is to develop a spatio-temporal pupillary representation through the use of the spontaneous pupillary oscillations signals (extracted from a video sequence) that are specific to the pupil of different people, and acquired at constant light conditions (without external stimuli). This natural dynamic behavior of the pupil will be the warranty that this template belongs to a living subject. The spatio-temporal representation of the spontaneous pupillary oscillations satisfies the following common biometric requirements: universality, distinctiveness, permanence and collectability.

Fig. 1. Spontaneous pupillary oscillations as a biometric trait

The major contributions of this work are:

The acquisition of the video sequence of 50 subjects and the creation of our own pupil video sequence set, the design of the experiment and the algorithms to extract and represent the pupil spatio-temporal features, the evaluation and demonstration of the potential discrimination among subjects based on the spatio-temporal representation of the spontaneous pupillary oscillations, the proposal of a mechanism of liveness detection based on the natural spontaneous pupillary oscillations induced at constant light conditions.

2 Background

Biometric traits are the human characteristics (physiological or behavioral) used by biometric-based application like identity access management, access control, surveillance, etc. [5]. The pupil is the circular aperture at the center of the iris which allows light from our environment to pass freely to the light-sensitive sensory cells of the retina. The size of the pupil is determined by the iris muscles, the radial dilator pupillae and the concentric smooth muscle circles of the sphincter pupillae, which work in opposition to dilate (mydriasis) and constrict (miosis) the pupil. [3,4]

The sphincter and dilator muscles are innervated by the Autonomic Nervous System (ANS) parasympathetic and the sympathetic pupillomotor fibers of the third cranial nerve, respectively. The sympathetic and parasympathetic systems work in opposition; a tonic activation in both systems balances each other to produce an average waking pupil-size in ambient illumination of 2-6mm, with an average of 5mm and a range of 1-9mm (Fig. 2).

Fig. 2. Muscles of the iris. Two opposite muscle groups within the iris of the human eye determine the aperture of the pupil.

It has been hypothesized, that the muscles controlling the dilation and contraction of the pupil are anatomically proper of the individual. In other words, such a complex system could exhibit high degree of uniqueness. As the iris has a trabecular structure capable of altering its size according to luminous stimuli, it is assumed that this feature can be altered differently in each subject, or that the evaluation of the pupillary fluctuations pattern can contribute to the recognition of a particular subject [18]. It has been demonstrated that the pupil/iris dynamic feature (DF) is discriminating, reason by which may be employed for personal identification. In addition, the possibility to extract this DF from living irises could avoid attempts of fraud in personal identification. [4,16,18].

As it was demonstrated by John Daugman in 2004 [21], the pupil, in most cases, is not a perfect circle; it is better approximated by an ellipse. Because the shape of the pupil is controlled by muscles (trabeculae), the contraction and dilation can change the size of the pupil, however the shape of the pupil remains same. [6,18].

Infrared video pupillography (IVP) combined with a special image processing and analyzing software offers the possibility of noninvasive stable long time record of pupil area and detailed analysis of changes of spontaneous pupillary oscillations. Person's eyes provide several useful biometric features both for the high security and user convenient applications. [11, 15, 17, 19]. Arguably, the most important feature in facial expression and animation are the eyes. [19]. The size of the pupil is determined by the iris muscles, the radial dilator pupillae and the concentric smooth muscle circles of the sphincter pupillae, which work in opposition to dilate (mydriasis) and constrict (miosis) the pupil. [4,17,18, 19, 21]

2.1 Spontaneous Pupillary Oscillations (HIPPUS)

The pupil area of the human eye continuously undergoes to small temporal fluctuations even in dark or under conditions of constant illumination, ranging in magnitude from 0 to 20%. This pupil activity, also called “hippus”, is a normal condition, is independent of illumination, convergence, or psychic stimuli (Fig.3). Hippus appeared to be spontaneous and seems most likely to occur when the subject is passive and left to himself. There is no doubt that hippus occurs in the absence of any light stimulus and in the pupils of both eyes, simultaneously and in phase. [2, 9 10, 13, 14].

As we had no preconceived hypothesis about whether and how the spatio-temporal features of pupillary signals are discriminative or not, in this work we present the preliminary verification results based on the spontaneous pupillary oscillations computing a spatio-temporal template recording the pupil area changes from a video sequence acquired at constant light conditions. A prototype image acquisition system was designed and developed to capture the pupillary hippus. In this work, we could detect liveness using as involuntary information mechanism the spontaneous pupillary oscillations. Our preliminary experimental results on a private database containing 50 subjects are presented.

Fig. 3. Typical example of spontaneous Hippus. At constant illumination, the average diameter of the pupil decreases as slow oscillations appear. When oscillations cease the pupil diameter returns to its initial value.

3 The Proposed Video-Based Method

Still-image recognition is routinely covered by existing research studies. However, video-based recognition approach is a relatively new research topic. The pupil video-based recognition method has superior advantages over the static image-based recognition [20]. Firstly, the temporal information of pupil images can be utilized to facilitate the recognition task (the person-specific dynamic pupil characteristics can help the recognition). Secondly, more effective representations can be obtained from the video sequence and used to improve recognition results. Thirdly, the involuntary characteristic of the pupil will be employed as a liveness detector. Finally, video-based recognition allows learning or updating the subject model over time.

Our proposed algorithm can represent the dynamic information of the spontaneous pupillary oscillations by a spatio-temporal biometric template and hence improve the recognition performance of the system. The proposed video-based biometric approach integrates a number of steps, each of which are explained in detail in the following sub-sections.

Pupil video acquisition, extraction of the Region of Interest, pupil region segmentation and representation, template matching.

3.1 Pupil Video Acquisition

A problem associated with the video-based technique is primarily that of getting a good view of the pupil. Head and eye movements can set up the image of the pupil

out of focus or out from the view field of the camera. So, if we want to obtain accurate measurements of a human subject's pupil, it is necessary that the subject remains absolutely still, thus, we employed a combined head/chin stand where the subjects rested their chin in such a way that the head position remains adjusted (Fig. 4). The study followed the tenets of the declaration of Helsinki.

Fig. 4. Experimental setup used for the proposed system [22]

The head/chin rest was mounted in a small table, approximately 20 centimeters in front of the infrared (IR) camera. In this way, the subject was able to feel comfortable and eventual eye movements would not appear. The alignment of the infrared camera was adjusted depending of the central position of the pupil in the screen. The accuracy of the IR video camera was greatly improved by fixing the head and eye position. [13,14]. Subjects were seated on a comfortable chair.

When (infrared) light arrives to the user's eye, several reflections occur on the boundary of the pupil, the so-called *Purkinje images*. This reflex can compromise the image quality of the pupil to be analyzed and segmented, so we positioned the IR video camera on a fixed place and instructed the subjects to look at the IR LED (2 mm in diameter) of the camera such that the reflex falls at the center of the pupil.

To reduce fatigue, and the potential effects of head or eye movements, each stage lasted 10 seconds approximately. The recordings started when the pupil image is located at the center of the screen camera and when the IR LED reflex appears at the center of the pupil. We acquired 20 infrared frames per video sequence per subject. Data were recorded from one eye only, typically the left eye. All the gray images were stored in *.jpeg format.

Another challenge in this approach is related to the detection and definition of the dynamic features of the pupil related to the light conditions, with the best discrimination potential among the subjects. The light luminance level was controlled in a quantitative manner using the visible light LEDs placed on the back of the campimeter, at a number of discrete stimulus locations out of the visual field.

We performed an exhaustive analysis on the spontaneous pupillary oscillations related to the ambient light conditions. After this, the selected luminance of the stimulus was 40 cd/m^2 . This was the highest luminance available on the experiment. As we were interested in evaluating the inter-person variations of the spontaneous pupillary fluctuations, we should factor out the possible influence of the light reflex in the pupil

(change in pupil size from the dark to light condition); therefore, complete dark adaptation was not necessary. In constant light condition, the amount of information obtained from subject's individual images is almost the same, so the data will be compatible.

Pupil images were recorded and transferred frame by frame by means of a video capture board providing real-time digitizing along the video sequences. The video-capture board was fitted by USB on a Pentium ® Dual-Core T4200 @ 2GHz and 4 GB of internal memory, and with a MATLAB 7.10 (R2010a) implementation to obtain real time recordings of the movie. The image size is 480 x 640 pixels.

Fig. 5. Samples of IR pupil images of 4 different persons; the bright spot in the middle of the pupil is the reflex of the infrared illumination LED used as the fixation point

We also developed a Graphical User Interface (GUI) which provides a real time visual feedback of the pupil images that is actually acquired. This GUI has the following functionality:

Assist the user in correct positioning of the pupil at the center of the screen and of the light reflex at the center of the pupil before the video recording starts, acquires the video sequence of the user's pupil, displays video sequences that were recorded previously, extracts the spatio-temporal representations from a given pupil video sequence, registers the user in the database along with the extracted spatio-temporal representation, checks whether a given video sequence of the pupil match any of the subject in the database, and updates a particular user's entry in the database by re-computing the spatio-temporal representation.

To preprocess the data, erroneous measurements were previously removed. These problems were caused mostly by involuntary blinking and in few cases from unintentional head and eye movements. Fig. 5 shows some examples pupil images of our database.

3.2 Extraction of the Region of Interest

Commonly, eye images without preprocessing are used to detect pupil region. This takes more time to process the image and in biometric applications the time of analysis plays an important role in the performance of the system. Therefore, before the feature extraction step, it is necessary to extract from the original images a specific portion to work with. This step is known as extraction of the Region of Interest (ROI) and let us to restrict the spatial image processing to the central region. This step reduces a lot the data amount without losing much useful information. This will speed up the following feature extraction and matching processes.

The proposed approach is based on the fact that all eyes' pupils are black round shaped, are far less covered by the eyelids than the iris and are located mostly at the center of the image. For simplify the process, we excluded the external regions, because they contain information that can compromise the image evaluation, such as eyelashes, eyelids, and sclera. The proposed algorithm scans only on the expected pupil's position. For finding the pupil region, the original image is reduced. For example, given a grey level image, we will divide the image by four equidistant horizontally and then by four equidistant vertically fringes, the first and last horizontal and vertical quarts are eliminated and we focus only on the central region. After this, a new image is provided with a clear pupil region that can be easily and quickly segmented and processed.

3.3 Pupil Region Segmentation and Representation

The low contrast between pupil and iris, usually, will harden the pupil boundary detection process and decrease the accuracy of its detection. The textural contrast between sclera and iris is high; conversely the texture contrast between iris and pupil is low. The problem is further aggravated with the presence of light reflection in the pupil [15].

The proposed pupil segmentation scheme relies on the fact that the pupil is round and is typically much darker than its surroundings. This is done using some morphological operations with a suitable thresholding detection procedure. Thresholding pupil detection procedures refer to an image segmentation method manipulating the statistical properties of the image brightness probability distribution (histogram). Hence, the reduced pupil image is preprocessed through the successive application of two morphological operations.

Fig. 6. Example of the image thresholding and pupil region segmentation method

Fig. 6 illustrates the outcome of each step of the pupil region segmentation stage. The measurement of the pupil area frame by frame is saved as the spatio-temporal representation of the pupillary oscillations. By taking into account all the frames in the video sequence, we initially proposed a feature vector with 20 elements.

3.4 Matching

After the extraction of features from pupil images, a matching metric is required to find the similarity between the probe and the gallery template. This metric should give one range of values when comparing templates generated from the same pupil (known as intra-class comparisons) and another range of values when comparing templates created from different pupils (known as inter-class comparisons). These two cases should give distinct and separate values so that a decision can be made with high confidence related to whether two templates are from the same pupil or from different pupils. The metric used for the proposed system is the Euclidean distance.

4 Experimental Results

4.1 Database Establishment

A particular own database was created for this study. We studied 50 healthy young subjects between 24 and 45 years old (20 females and 30 males); most of the subjects were university students and employers. The consent to participate in this study was obtained from each subject after the nature of the procedure was completely explained to them. We collected 1000 grayscale left eye images from 50 persons, 20 from each person. The size of all eye images in the database is 480×640 pixels. Experiments were conducted in a quiet usability laboratory. The video sequences were collected in a resting condition with subjects seated on a comfortable chair.

4.2 Evaluation of the Segmentation Method

We visually evaluated the success of the proposed pupil thresholding and segmentation method for all the 1000 images. The pupil region was correctly detected in all the images getting a success rate of 100%. The proposed method is robust enough because: a) the head/chin rest avoid the involuntary head movements, b) the alignment of the IR camera guaranty that the pupil region is almost always at the center of the video frame and c) the pupil region is not affected by the eyelid and eyelashes noise. Evaluation of the inter-individual differences

The spontaneous pupillary oscillation-based verification system was tested using our own database of 50 users. As was mentioned previously, the measurement of the pupil area frame by frame is saved as the spatio-temporal representation of the pupillary oscillations. 20 images of each user's pupil were used to compute the feature vector fusing it with the user's abbreviation name and birthday and then were stored in the database.

To better evaluate the inter-subject variability in spatio-temporal pupillary oscillations, it seemed useful to plot the individual feature template of 20 of the users using the Chernoff faces mapping the spatio-temporal dynamic features of the pupil to the attributes of the cartoon faces (area and shape of the face, length of the nose, location of the mouth, curve of the smile, width of the mouth, location, separation, angle, shape and width of the eyes, location and width of the pupil, and location,

angle and width of eyebrow). We found great inter-individual differences with regard to the extent as reflected in these cartoon faces.

4.3 Experimental Results on Spontaneous Pupillary Oscillation Verification

To obtain the verification accuracy for the spatio-temporal pupillary template, we computed the false acceptance rate (FAR) and false rejection rate (FRR) at different match thresholds. For this, each pupil video sequence is matched with the feature vector stored in the database associated with the claimed identity. The verification is positive if the distance between the query and the stored feature vector is lower than the threshold value, otherwise is considered as a non-matched vector. The FRR decreases from 0.102 to 0 whereas FAR increases from 0 to 0.9463 as the threshold value increases from 1 to 7. In a pilot experiment, for the privately collected database we noticed that the FRR and FAR intersect at the point [5.813, 0.004356] which represent the EER.

5 Conclusions

This work introduced a new pupillary video-based spatio-temporal verification system. We also presented the initial identity authentication results based on the pupil dynamic features extracted from a video sequence which was acquired at constant light conditions. This paper reports the preliminary results conducted by using an IR-camera, a head/chin rest and a campimeter in laboratory conditions. We demonstrated that this biometric characteristic provide enough discriminative information to verify the identity of a subject. We described the methodology to compute a spatio-temporal feature vector recording the pupil area changes frame by frame from a video sequence acquired at constant light conditions. The pupil region was correctly detected in all the images getting a success rate of 100%. The proposed method is robust enough because: a) the chin rest avoid the involuntary head movements, b) the alignment of the IR camera guaranty that the pupil region is almost always at the center of the video frame and c) the pupil region is not affected by the eyelid and eyelashes noise. We found great inter-individual differences with regard to the extent as reflected in the Chernoff cartoon faces. In preliminary experiments, for the privately collected database, we observe that Equal Error occurs at a threshold of 5.812 and the error is roughly 0.4356%.

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