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Using iris and sclera for detection and classification of contact lenses☆

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ABSTRACT

Detecting the presence of contact lenses and their type helps increasing the reliability of iris-based authentication systems. We propose a machine-learning approach for this task, based on expressive local image descriptors. The image is first segmented to extract the iris and sclera regions, then scale-invariant local descriptors (SID) are computed densely on both areas, and summarized through the Bag-of-Features paradigm. Classification is based on a properly trained linear SVM. The major contributions of our proposal concern the segmentation algorithm, the use of information drawn from the sclera, and the use of non-rectified data to preserve local structures. A number of variants of the proposed method are investigated, working on different areas of the image, with alternative local descriptors, and with different encoding techniques. Eventually, results are compared with the state-of-the-art in the field. The experimental analysis, carried out on several publicly available datasets, shows that the proposed classification method based on a dense scale invariant descriptor outperforms all the reference techniques.

1. Introduction

Iris-based biometric authentication systems are becoming extremely popular thanks to their high reliability in both identification and verification tasks [5,11,27]. This is essentially due to the properties of the iris pattern, which is unique even for identical twins, and so rich of distinctive features that a casual wrong identification is seldom observed. Moreover, as an internal organ of the eye, the iris is well protected from the environment and stable with age [10].

The performance of iris recognition systems, however, can sharply degrade when the users wear contact lenses. The impairment is quite significant in the case of *cosmetic* lenses, used to modify the appearance of the iris, so as to alter its color and possibly also its texture [9]. However, it may be non-negligible also for *transparent* lenses, as recently shown in [2], due to induced artifacts. For example, the lens generally moves around on the eye's surface, causing several artifacts that prevent a correct matching and increase the false rejection rate in the identification task. Hence, to improve iris recognition, it is important that the system be able to recognize whether the user wears contact lenses, and of which type, cosmetic or transparent.

Some examples of such images coming from the IIIT-D contact lens database [21] are shown in Fig. 1. It can be seen that cosmetic lenses have, typically, a very marked texture, more visible than that of natural irises, suggesting that they can be easily recognized based on the analysis of the iris region. Indeed, the iris with its complex structure, provides abundant textural information to exploit for classification purposes. On the contrary, transparent lenses, and in particular soft lenses, do not alter the characteristics of the iris. However, unlike in the no-lens case, a boundary of circular shape is always present, more or less visible, in the sclera region. We argue that these differences can be well captured by a fine-scale statistical analysis conducted over small patches of the images, provided that also part of the sclera region is examined.

In particular, in this work we use a Bag-of-Features paradigm where dense local features are extracted from all patches of the region of interest and jointly quantized for the classification task. This approach has proven very promising for detecting the biometric spoofing of different traits [15]. The regions of interest are extracted by means of an *ad hoc* segmentation algorithm. We take into account information coming both from the iris and from part of the sclera region, in order to detect both textured and transparent lenses. Moreover, in order to prevent any type of texture distortion, we avoid any normalization.

Preliminary results of this work were presented in [14]. With respect to that paper, the current version is largely improved under several points of view: (i) new versions of the proposed algorithm have been devised and analyzed; (ii) a more thorough assessment of the segmentation algorithm has been carried out, through the inclusion of new specific datasets; and (iii) the comparative assessment of classification results, conducted on the same datasets used in [48], includes a further technique very recently published. Such new

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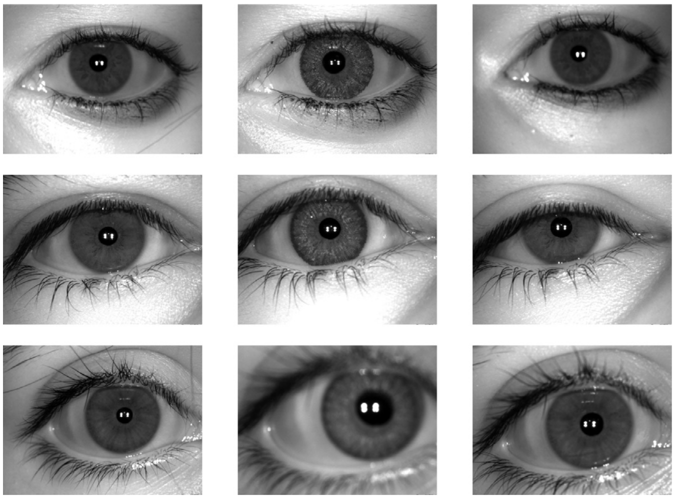

Fig. 1. Example images of iris with no lens (left), cosmetic lens (middle) and transparent lens (right). Samples are taken from IIIT-D Cogent dataset.

data provide a better insight into the effectiveness of the proposed method.

The rest of the paper is organized as follows. In Section 2 the current literature on this topic is reviewed. Then, in Section 3, our approach is described in detail, while the experimental results are reported in Section 3.1. Eventually, Section 4 draws some conclusions.

2. Related work

Most of the research on this topic focuses on colored lenses, since they can be also used by a malicious user to attack the system. Fakes made by cosmetic lenses are the most challenging to detect, since, differently from printed-iris attacks [39], the alteration is localized in a very small part of the image.

A pioneering work in this direction is due to [10] where irises are detected by means of the periodicities left by the dot-matrix printers used in the fabrication process. Another method, proposed by Park [31], checks the dilation or contraction of the pupil (hippus movement) as a response to specific stimuli (light off/on). In a recent paper, Czajka [7] also highlights the importance of pupil dynamics for iris liveness detection, given the difficulty to mimic them for artificial objects. Both these approaches are based on machine learning. The former extracts some global features, like standard deviation and energy, in the wavelet subbands. The latter defines seven liveness features useful to model the natural reactions and spontaneous oscillations of the pupil. A major drawback of these methods is their need to analyze a time series of at least 2 s. In addition, the variation of the pupillary light reflex decreases with age [47] and can have a different behavior after ingestion of particular substances, like drugs and alcohol, or when people are stressed or completely relaxed. A different perspective is adopted by Hughes and Bowyer [18], based on the estimation of the surface shape of the imaged iris region, and requiring a second camera to allow stereo imaging. It is shown that in case of cosmetic lenses the iris region has a smooth, convex shape. Note that all these methods require additional hardware to be embedded in the iris recognition system. Moreover, they are completely ineffective to detect transparent lenses.

Just a few papers focus on the problem of detecting non-cosmetic contact lenses. Kywe et al. [24] observe that there are variations of temperature on the surface of the eye caused by evaporation of water during blinking and these variations are different if subjects wearing contact lenses. This solution however requires a thermal camera and is highly dependent on the environment temperature and humidity. In [12], instead, a software-based approach is considered, based on the hypothesis that the boundary of a soft contact lens is at least partially visible in the sclera. This part of the boundary is detected by examining the intensity profiles of the pixels located near the outer limbus boundary of the iris.

Actually, software-based methods are generally more flexible and represent a good trade-off between performance and cost. In particular, approaches based on the use of local descriptors for the analysis of micro-textures are extremely promising [15]. In [45] different measures are proposed: iris edge sharpness, iris-texton features based on Gabor filters, and features based on co-occurrence matrix. Local binary patterns (LBP) [30], extracted at multiple scales, are instead used in [16], while in [49] the SIFT descriptor [26] is used to guide the LBP encoding procedure after a preliminary denoising. Variants of LBP are adopted in [48], which is the first work facing the problem of distinguishing cosmetic and transparent contact lenses from natural irises. In [41] dense SIFT descriptors are used starting from the gradient image. Recently, Komulainen et al. [23] and Raghavendra et al. [35] proposed to use BSIF features [20], that proved already successful for fingerprint liveness detection [13], while in [40] a convolutional neural network is considered.

Besides the specific descriptor used, these techniques differ significantly in the pre-processing phase, designed to select one or more regions of the eye image where relevant information can be extracted, and to discard data of no diagnostic value. In [45] and [41] the features are extracted only from the iris region, resampled in polar coordinates (a process called *normalization* in this field) so as to deal with more manageable rectangular images. In [16] the normalized iris is divided into six-subregions, corresponding to different scales of observation and orientation, computing and concatenating features for each region. In [49] and in [23], instead, no normalization is applied, to better preserve the textural differences. In particular, Komulainen et al. [23] show experimentally that performance improves if the original cartesian images are processed. Features are then computed in a square region bounding the iris, thereby including part of the sclera. This region turns out to be extremely important to recognize transparent lenses, which could originate some image artifacts near the iris external boundary [12]. The importance of collecting information also from the sclera and the pupil regions is explicitly recognized in [48] where, after normalization, LBP features are extracted independently from all regions and concatenated. Also in [35] the information contained in the sclera is used in the detection process by considering BSIF features extracted from three different regions. Then the scores obtained separately through an SVM classifier are combined by a weighted majority voting.

3. Proposed approach

In this section we describe the proposed method, which comprises three major steps: segmentation of the iris and part of the sclera region, dense feature extraction and classification by means of the Bag-of-Features paradigm.

3.1. Segmentation

Segmentation is a fundamental step in iris-based recognition systems. It comprises several tasks: finding the iris pupillary and limbic boundaries, localizing the upper and lower eyelids and, not least, excluding regions with shadows, reflections, or occluded by eyelashes. This can be a very challenging task, especially for noisy images and non-cooperative acquisitions. Among the many approaches proposed in the literature, the most popular rely on an integro-differential operator to localize iris boundary [8], or else on the Circular Hough Transform (CHT) [46].

Here, we follow this second approach, building upon the parametric algorithm recently proposed in [37] which is characterized by low complexity and good performance. We aim at detecting the arcs