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Local contrast phase descriptor for fingerprint liveness detection

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ABSTRACT

We propose a new local descriptor for fingerprint liveness detection. The input image is analyzed both in the spatial and in the frequency domain, in order to extract information on the local amplitude contrast, and on the local behavior of the image, synthesized by considering the phase of some selected transform coefficients. These two pieces of information are used to generate a bi-dimensional contrast-phase histogram, used as feature vector associated with the image. After an appropriate feature selection, a trained linear-kernel SVM classifier makes the final live/fake decision. Experiments on the publicly available LivDet 2011 database, comprising datasets collected from various sensors, prove the proposed method to outperform the state-of-the-art liveness detection techniques.

1. Introduction

Biometric systems are commonly used for authentication in various security applications. By relying on features that are unique for each individual (iris, fingerprints, etc.) they guarantee simplicity and reliability at the same time, avoiding the typical problems of systems based on the use of passwords, which can be forgotten, stolen, or figured out. Of course, biometric systems have their own weaknesses. In particular, they are relatively vulnerable to some sophisticated forms of spoofing. Fingerprint-based systems are among the most commonly used and, for this very same reason, more subject to attacks. Indeed, early systems could be easily fooled by fake fingerprints, reproduced on simple molds made of materials such as silicone, Play-Doh, clay or gelatin [1,2].

A large number of methods have been proposed in recent years to combat spoofing. Some of them rely on dedicated additional hardware embedded in the sensor which confirms the vitality of the fingerprint by measuring temperature, odor, pulse oxiometry, etc. [3,4]. Since this approach can use different sources of information, it turns out to be more resilient to generic attacks, and typically guarantees a very good reliability. Nonetheless, this is a relatively expensive and rigid solution, and for these reasons has gained little popularity.

Software-based methods, based on signal-processing techniques, are certainly more appealing, for their reduced cost and invasiveness, and their higher flexibility. They try to detect vitality by analyzing synthetic image features that are peculiar of vital fingerprints and not easily reproduced on fakes. Such features are typically singled out based on a deep study of the physics of the problem and/or a careful analysis of the statistical behaviour of the captured images. A large number of such methods have been proposed in recent years [5–19], based on clever and well-founded ideas, testifying on the relevance and difficulty of this problem.

In parallel with these approaches based on a *global* description of fingerprints, though, techniques based on machine learning and *local* descriptors have been taking hold recently for fingerprint liveness detection [20–24]. Local descriptors, as the name suggests, describe the statistical behavior observed locally in very small patches of the image by means of histograms (frequencies of occurrence, empirical probability distributions) collected over the ensemble of all patches. These histograms are then used as features to classify the images by means of conventional classification approaches. Techniques based on local descriptors provide usually a *much better* performance than the previous class of methods. It is somewhat surprising that these alternative methods, showing often little or no fingerprint-specific clues, overcome the global-descriptor approaches. On the other hand, liveness detection, as all tasks related with digital security, can be seen as a game with two players, and it is only reasonable to expect that methods based on coarse features will be sooner or later tricked by smart attackers equipped with better materials and better knowledge of the fingerprint statistics. Local descriptors represent a natural evolution towards the discovery of fine features that are more discriminating and also harder to tamper with.

Till now, however, only general-purpose descriptors have been considered for this task, while descriptors conceived specifically for fingerprint images could very likely provide a still better performance. In this work, we move some steps towards this goal. Building upon previous work in this field, we propose a new local descriptor based on spatial-domain and transform-domain features which appear to be very discriminating for liveness detection. An appreciable performance gain w.r.t. the state of the art can

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be observed on standard and publicly available datasets, which is an encouragement to further pursue this line of work.

The rest of the paper is organized as follows: in Section 2 we briefly review the literature on fingerprint liveness detection, with special focus on techniques based on local descriptors, then in Section 3 describe the proposed approach, and in Section 4 present the results of some numerical experiments. Eventually, in Section 5, we draw conclusions and outline future researches.

2. Related work

2.1. Conventional methods

Because of imperfections in the material used, spoofed fingerprints exhibit usually a worse quality than the live ones. Based on this consideration in [6] the coarseness of the fingerprint is used as a discriminative feature. After subtracting a denoised version of the image from the original one, the variance of the noise residual in detail wavelet subbands is considered as a measure of coarseness and used for classification. Also in [18] quality-related measures are used for fingerprint liveness detection. In this case the work focuses on some fundamental properties of ridges, like the strength, the continuity and the clarity, collecting a set of 10 features. The same approach is pursued in [19] where 25 quality measures are proposed to perform discrimination.

Besides image quality, more fundamental and intrinsic properties of fingerprints can be taken advantage of. In particular, the fingerprint pattern is comprised of ridges, touching the sensor plane, and valleys, which remain far from it, and this ridge-valley structure typically looks different for fake and live images. In [16], for example, ridges and valleys are extracted using a mask, and separate related features are computed in both the spatial and transform domains, and eventually fused to perform classification.

Analysis in the Fourier domain, and more recently in the wavelet transform domain, is indeed one of the strongest assets in fingerprint liveness detection. In particular, transform-based methods drawn from the texture classification literature can be easily adapted to deal with fingerprints which, due to their strong regular structure, can be assimilated to textures themselves. These methods work on the energy spectrum of textures, assuming that different classes of texture exhibit different distributions of energy in the transform domain [25]. In [10, 11], in particular, it was observed that the different ridge–valley periodicity of live and fake fingerprints translates into easily captured differences in their spectral ring patterns. Live fingerprints have higher energy content in the ring patterns than their fake counterparts, a property readily used for reliable classification. Other features related to spectral energy distribution have been proposed with reference to different transforms, like wavelet [8] and ridgelet [14], with similar results.

In the literature, much attention has been also devoted to the phase, which is able to better preserve the correlation between neighboring samples [26] and, when evaluated locally, can give a more precise localization of patterns. Short-time Fourier transform (STFT) and the more general Gabor filter banks both capture well this type of information. Especially the latter has been extensively used to characterize textural information in different areas, and in particular for biometric feature identification [27–29]. The differences arising in inter-ridge distances, ridge frequencies and widths between live and fake fingerprints seem to be well captured by textural features extracted using Gabor filters, as shown in [12]. However, in this last work only global features are considered using second order statistics.

Morphology-based and perspiration-based features have been taken into account in [17], where a proper feature selection approach is also adopted. Other interesting features, related to skin deformation [9] or pore perspiration [5,7,15] , have also been considered, but have drawn limited attention since they require multiple acquisitions of the same finger.

2.2. Methods based on local descriptors

Local descriptors have gained an ever growing attention in the last decade, starting with the seminal Local Binary Patterns (LBP) descriptor proposed in [30]. A long score of successes in very different and challenging tasks, such as face recognition [31], fingerprint recognition [32], camera identification [33], or image forgery detection [34], testifies on the potential of these tools. More in general, patch-based processing is becoming a dominant paradigm in all branches of image processing and machine vision, from image denoising [35,36], to no-reference measures of image quality [37], to texture classification [38].

Local descriptors first appear in the fingerprint liveness detection literature in 2008, in a paper [20] where wavelet-domain energy features are complemented by the LBP descriptor. After this first work, and despite its pretty good results, several more years passed before researchers of this field began to focus on these powerful tools. A significant stimulus came, very likely, from the LivDet competitions [39–41], which provided a common database to test the performance of competing algorithms. In [23], following [42], a multiscale version of LBP was proposed. The LBP operator was applied with large radii, after a regularizing low-pass Gaussian filtering, so as to take into account long-range dependencies. In [21] we find the first attempt to use the local phase for the purpose of fingerprint liveness detection, with very good results, by using the Local Phase Quantization (LPQ) descriptor [43,44]. In [22] the Binarized Statistical image Features (BSIF) [45] was tested for liveness detection. Rather than using a fixed set of filters, BSIF learns its own using the statistics of image patches and maximizing the statistical independence of the filter responses. In [24], the use of Weber Local Descriptor (WLD) [46] was investigated, also in combination with other descriptors. Very recently, a Wavelet-Markov local descriptor was also proposed in [47].

Despite the excellent results obtained, these proposals show little or no effort to adapt the descriptors to the specific fingerprint problem, and the experimental results do not point out any *killer* features, related to some physical or statistical trait of the data. A common effort, however, is to combine several descriptors [21,24], as also done in other fields, using information coming from the space, frequency, and orientation domains [48], or concatenating the LBP and LPQ features [49]. In particular, in [24] we tested several popular descriptors, i.e., LBP, WLD and LPQ, for the liveness detection problem. In that context, we also tested the descriptors obtained by concatenating the basic ones, that is, by forming a new feature of length $\sum_i N_i$ by simply putting together several features of length N_i. Experiments were extremely informative. A first striking result, already mentioned in the Introduction, was the gap in performance gain provided by all classifiers based on local descriptors w.r.t. all other classifiers. Moreover, we observed a further significant gain when we tried some simple concatenations of descriptors. This was not obvious, a priori, because adding features increases dimensionality, a problem to be dealt with through some feature selection techniques. The performance improvement indicates that the new features are indeed discriminative or, more precisely, that the selected concatenation allows for a better exploration of the whole data space.

However, not all concatenations provided an equally good performance, and this shed some light on their respective importance. In particular, results showed that the phase-oriented features encoded by the LPQ descriptor hold a major discriminative power for this task. In hindsight, this is no surprise, considering the quasi-sinusoidal local behavior of fingerprint images, and the