Combining Wavelet Transform and LBP Related Features for Fingerprint Liveness Detection

Zhihua Xia, Chengsheng Yuan*, Xingming Sun, Decai Sun, Rui Lv

Abstract—**Fingerprint authentication system may verify the identity of the user according to the features of fingerprint. It has been widely used in government departments and national security departments. However, there are some security and privacy problems: Fingerprint authentication system may be easily tricked by fake fingers which are produced through using common artificial materials, such as silicon, wood glue and latex. Thus, designing a fingerprint liveness detection module is necessary for authentication system. In this paper, in order to obtain the optimal set of features and recognize fake fingerprints, a new software-based liveness detection approach using a novel fingerprint parameterization based on wavelet transform and local binary pattern (LBP) related features is applied. The performance of our proposed approach has been evaluated through a comparison with several state-of-the-art techniques for fingerprint liveness detection. In addition, the liveness detection method presented in this paper has an extra advantage over previously studied techniques, since only a fingerprint image is needed to judge whether it is real or fake. Experiments have been carried out by adopting standard databases which are taken from the Liveness Detection Competition 2011 and 2013. Besides that, we have also analyzed the performance of our method for the different combination of wavelet decomposition coefficients during the process of training. Finally, classification accuracy of feature vectors is predicted based on a SVM classifier. Experimental results demonstrate that our method can detect the fingerprint liveness with higher classification accuracy. In addition, this study also confirms that multi-resolution analysis is a useful tool for the extraction of texture feature during fingerprint images processing.**

Index Terms—**Fingerprint, Liveness detection, wavelet transform, local binary pattern, Support Vector Machine**

I. Introduction

WITH the advent of biometric technology, the security of authentication system has become an important issue than ever before. Biometrics authentication system refers to the identity identification based on their physiological and behavioral characteristics. Therefore, biometric recognition systems are commonly used for authentication in various security applications. The ease of use and low error rates which promote their widespread use are superior to others methods. However, biometric systems have also their own weakness, such as biometric systems contain vulnerabilities and are also susceptible to various kinds of artificial reproduction. Among these, the fingerprint recognition, the ease of use and high correct rate, accounts for the vast majority part[1]. Indeed, early identification systems can be easily spoofed by fake fingerprints, which can be reproduced from common materials. Popular fake fingertip materials such as silicon, wood glue and latex [2, 3] consist of large organic molecules which tend to agglomerate during processing. For example, the threats of fingerprint authentication systems are including: spoof finger can cheat and access the system at the sensor, spoof finger can cheat and access the system on software modules, etc [4].

The ability of fingerprint authentication system to discriminate whether the fingerprint samples presented are really from a live finger tip or spoofed one, which is called liveness detection. In order to prevent spoofing, many kinds of detection methods have been proposed [5-8] in recent years. Texture is an important feature used for identifying regions of interest (ROIs) of an image, which can express either the fine structure or the macroscopic structure. In traditional detection methods, they can be broadly divided into two approaches: Hardware-based methods applied at acquisition stage, and some of them rely on dedicated additional hardware embedded in the sensor which confirms the vitality of fingerprint by measuring fingerprint temperature, pulse, blood pressure, electric resistance and odor, etc [9, 10]. Using the different sources of information, it turns to be more robust to common attack and it can guarantee a quite good reliability. However, improper integration of additional sensors can cause higher error rates of liveness detection and the system structure becomes more complex. Software-based approach, applied at processing stage[11,12], are more popular, since their lower cost and their higher flexibility. They try to detect liveness by analyzing image features, which are peculiar of real fingerprints.

The features used to distinguish between real and fake fingers are extracted from the fingerprint. There are methods such as in [13] and [14], in which the features used in the classifier are based on the specific fingerprint measurements, such as ridge strength, continuity and clarity. In parallel with these methods based on a global description of fingerprints, though, techniques based on machine learning and local descriptors have been taking hold recently for fingerprint

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liveness detection [15-17]. A local descriptors, as the name suggestion, describe the statistical behavior observes locally in very small patches of the image by the means of frequencies of occurrence collected over the ensemble of all patches. These frequencies of occurrence are used as features to classify the images by the means of conventional classification approaches. Based on local descriptors usually provide a much better performance than the previous class of methods.

The current fingerprint liveness detection research is concerned about how to design a better feature extraction approach. Existing algorithms are limited by their learning-based nature which is implies dependence on both the sensor used for acquiring data and specific set of material used for representing the spoof class when training [18]. In recent years, researchers have proposed many texture features extraction methods based on analysis of multiple scales according to human vision. In this paper, we propose a novel fingerprint liveness detection algorithm based on wavelet transform and Local Binary Pattern. Multi-resolution analysis has been proved to be useful for image processing. On the whole, we regard fingerprint liveness detection as two-class classification problem, in which a given fingerprint image is either a live fingerprint or a spoof one. Feature extraction is an important step during the process of classification. In the proposed approach, by using a wavelet transform, it can divide the same energy of the original fingerprint image into the same coefficient after wavelet decomposition. These coefficients have local corelation in three different directions sub-band coefficients: horizontal, vertical, and diagonal. The goal of multi-resolution transformation is to decompose the original image into different sub-bands coefficients that preserve high-frequency and low-frequency information respectively, then analysing these sub-bands in the frequency domain. After these, feature vectors of each of sub-bands images are constructed through using Local Binary Pattern (LBP). Once the feature vectors have been constructed, the sample is classified as real or fake using the classifier: support vector machine. Results show that our proposed method shows a better performance.

The paper is organized as follows. In Section II a summary of the most relevant concepts to the present study is given. Our proposed method about the feature vector extraction is introduced in Section III. The result and comparison are given in Section IV. Conclusions are finally drawn in Section V.

II. RELATED WORK

Fingertips surfaces are intrinsically coarse at certain scale because of the alternation of the ridges and valleys on them. In order to estimate the surface coarseness, wavelet transform technology is used since it get the same frequency coefficient together. Many texture features extraction methods from fingerprint images have been proposed. To illustrate these features, we simply divide software-based methods into five categories: Perspiration-based, Texture Feature-based, Image Quality-based, Pore-based and Skin Deformation-based, which have been adopted by many researchers, such as [19-23].

Perspiration-based methods: Because sweat glands can produce moisture, the real fingerprint images from fingerprint devices will change slightly in a short time span. Nevertheless, the obtained spoof ones from sensor devices can not generate moisture. Therefore, researchers detect the fingerprint vitality through the study of Perspiration. In [6,7], it was observed that the perspiration pattern change at different time interval (2 seconds in [6] and 5 seconds in [7]). In [26], Gray-level values along the ridges are taken into account using ridge signal algorithm via mapping the two-dimensional fingerprint images into one-dimensional signal. In their method, they can find that the longer the time interval, the more complex wavy nature based on the spreading of moisture in the live fingerprint. In order to solve the problem and improve the accuracy of Derakhshai's proposed method. Abhyankar et al. [8] proposed a novel liveness detection method which can isolate the perspiration pattern by using wavelet analysis. In their method, multi-resolution analyses extract the low frequency content and wavelet packet analysis extract the high frequency content. In particular, transform-based methods can be easily adapted to deal with fingerprints which can be assimilated to textures themselves. Other features related to spectral energy distribution have been proposed with reference to different transforms. After that, Tan and Schuckers [9] also proposed a method based on quantity perspiration to detect the fingerprint liveness. The method quantifies gray level differences of live or spoof fingerprint images through analyzing histogram distribution statistics.

Skin Deformation-based methods: It is true that the defamation of live fingerprint is higher than spoof ones when touching the surface of scanner. Therefore, the properties obtained based on the deformation can be considered as the features of fingerprint image. Zhang et al. [10] proposed a liveness detection method based on thin-plate model which can capture finer distortion. In their method, in order to capture a sequence of frames, the testers were asked to press the surface of scanner and rotate their fingers in four directions (0, 90, 180, and 270). Then, relevant features are extracted based on the skin deformation-based from capturing finger distortion images. In [11], Jia et al. proposed a liveness detection method using one-way analysis of variance ANOVA and Multiple Comparison Method to do the statistical tests on the dataset of real fingers and fake ones. In their method, the tester needs to put his fingers on the scanner devices, then, a sequence of fingerprint images is captured. The features are extracted from the sequence of images. No extra hardware or special finger movement is required in this method.

Image Quality-based methods: Generally, because of imperfections in the material used, artificial spoofed fingertips exhibit usually a worse quality than the real ones. Since fake fingerprint image quality is not as good as the real fingerprint image, it is difficult to forge a real fingerprint image with the same or better quality fingerprint images. Based on this consideration in [24] the coarseness of the fingerprint is used as a discriminative feature. Nikam and Agarwal [12]checked the liveness of fingerprint based on ridgelet transformation to extract image texture features using only one fingerprint image. "A texture of an image describes visual information related to local spatial variations of gray level intensities and orientations" [13]. The same method is proposed in [25] where 25 quality parameters are proposed to perform discrimination. Tan [14] proposed a fingerprint vitality detection method based on wavelet analysis. In their method, they observed that spoofed fingerprint has some different noise along the fingerprint valley, while the ridge-valley structure of live fingerprint along the fingerprint valley is clean. The quality features are extracted via using this approach. In 2013, Pereira et al. [15] detected the vitality of fingerprint images based on residual Gaussian white noise of the fingerprint images to estimate the coarseness of fingerprint image.

Sweat Pore-based methods: There are many small pores of circular structures in real fingertips, while the researchers observed that we cannot accurately imitate sweat pores in spoofed ones. In [16], Espinoza proposed a new method to detect fingerprint liveness by comparing pore quantity between recorded fingerprints and the query ones. Since pores can be considered as signal of fingerprint liveness, [15] proposed a new method based on analysis of pore. Their paper applies two filtering techniques: highpass filter which was used to extract active sweat pores and correlation filter was used to locate the position of pores. After that, Memon [17] proposed a novel detection method based on the optimum threshold from a correlations peaks to detect which peaks are active pores. In 2010, Manivanan [18] also proposed a vitality detection method based on detecting pores.

Texture Feature-based methods: More fundamental and intrinsic properties of fingertips can be used. In particular, fingerprints are composed of ridges and valleys, and the structure of ridge-valley of live fingerprints is different from spoof ones. Therefore, texture features used for indentifying regions of interest (ROIs) are important feature in fingerprints. Many methods have been developed for analyzing texture, such as statistical, structural, model-based and signal processing approaches[19]. Abhyankar [20] developed a fingerprint vitality detection method based on minimize the energy associated with phase and orientation maps. In their method, multi-resolution texture feature analysis and cross ridge frequency analysis techniques are applied. Frassetto [21] extractd texture features by an algorithm based on the spatial gray level dependence method, which proposed using the statistical texture analysis of a fingerprint by using spatial gray level dependence method (SGLDM) for personal verification and discrimination. In literature, much attention has been also devoted to the wavelet transform domain, which is indeed one of the strongest assets in fingerprint liveness detection. Nikam proposed many fingerprint liveness detection methods, such as the curvelet transform [22,23] , the Gabor filters[24], and the gray level co-occurrence matrices which is combined with the wavelet transform [25,36]. In 2014, Diego Gargnaniello [26] proposed a liveness detection based on spatial domain and transform domain. In their method, to extract information on the local behavior of the image, and on the local amplitude contrast, they needed to analyze the input fingerprint image both in the spatial domain and the frequency domain.

III. Feature Extraction

The problem of fingerprint detection can be seen as two-class classification problem where an input fingerprint image has to be assigned to one of two classes: real or fake, so the extraction of image features is the key point. A general diagram showing different phases of our approach is shown in Fig 1, which mainly including two phases: image training process phase and image testing process phase. In our method, we propose a novel method based on two methods of wavelet transform and Local Binary Pattern (LBP). The feature vectors are constructed by our method. Finally, with the help of SVM classifier, the SVM predictor can divide the fingerprint images into two classes automatically. Compared with the existing state-of-the-arts livenss detection solutions, our method can reduce the use of memory space, since the dimensionality of extracted features is small. Moreover, it is cheap and convenient to embed in hardware, while the experimental results present that our approach can achieve a better classification accuracy. Next we will provide details on feature extraction of image.

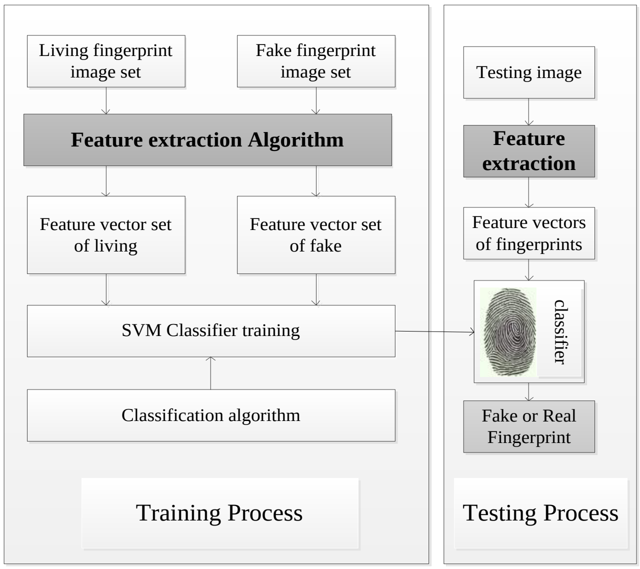


Fig 1. The flowchart showing different phases of our approach

A. *Wavelet Transform (WT)*

A wavelet transform is one of most popular tools for the signal transformation of time-frequency. The fundamental idea of wavelet transformation is that the transformation should allow only changes in time extension, but not shape. Since wavelet transform is a local descriptors of space (time) and frequency, it can extract features from images effectively. This is affected by choosing suitable basis functions that allow for this, such as Haar, Daubechies, Morlet, Meyer, Symlets, Morlet. Compared with Fourier transform, wavelet transform can deal with multi-scale analysis through scaling and translation operation. For example, the two-dimensional Daubechies can decompose approximation coefficients $A_k(m, n)$ scale k into four components: the approximation coefficient $A_{k-1}(m, n)$ and three high frequency coefficients at scale k-1, i.e., the horizontal wavelet coefficients are D^1_{k-1}(m, n), the vertical wavelet coefficients are D^2_{k-1}(m, n) and the diagonal wavelet coefficients are D^3_{k-1}(m, n).

In Daubechies algorithm, the decomposition of wavelet transformation is as follows:

$$\begin{cases} A_{k-1}(m,n)=\sum_{i,j} h^1_{i-2m} h^2_{j-2n} A_k(i,j) \\ D^1_{k-1}(m,n)=\sum_{i,j} h^1_{i-2m} g^2_{j-2n} A_k(i,j) \\ D^2_{k-1}(m,n)=\sum_{i,j} g^1_{i-2m} h^2_{j-2n} A_k(i,j) \\ D^2_{k-1}(m,n)=\sum_{i,j} g^1_{i-2m} g^2_{j-2n} A_k(i,j) \end{cases} \quad (1)$$

In which h^1_{i-2m} , h^2_{j-2n} , g^1_{i-2m} , g^2_{j-2n} are low pass filter and high pass filter of wavelet decomposition transformation, and they are related to the wavelet basis; (m, n) denotes the point coordinate. The maximums are separated M in the image size $M \times M$. The decomposition process is shown in Fig 2. As we can see in Fig 2, firstly, the original signals are decomposed into two parts according to the line transformation. Secondly, the decomposition of two parts is done decomposition according to the column transformation. In our proposed method, down-sampling is done in order to reduce the dimensionality of feature vectors. Finally, the approximation coefficient and the detail coefficients in three orientations at scale k-1 are quarter size of the approximation coefficient at scale k .

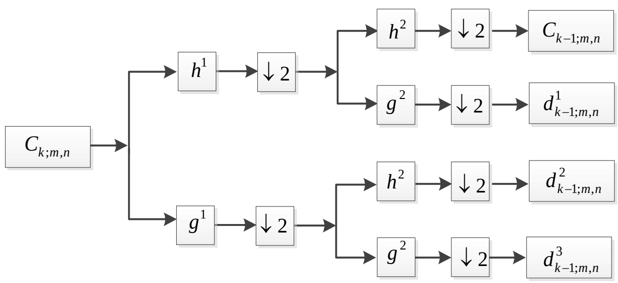


Fig 2. The coefficient-decomposition flowchart chart of Daubechies arithmetic

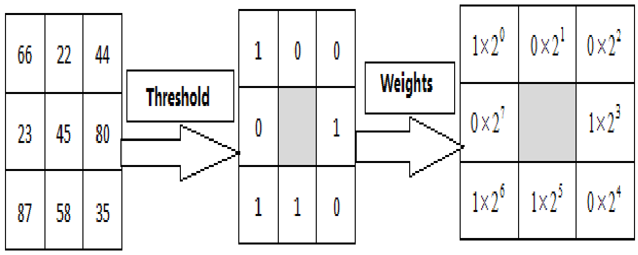
B. Local Binary Pattern

LBP (Local Binary Pattern), which is an effective operator, is used to describe the local texture feature of original images. It can extract the texture features of gray image. Firstly, in 3 × 3window, the pixel values of eight neighbors are needed to be compared with the value of the center pixel respectively, and we can calculate the binary relations by using Eq. (2). Then, the binary relationship is weighted into a LBP code by powers of two and summed to obtain the LBP code of the center pixel. Eq. (3) can calculate the LBP code. In Eq. (2), z denotes the difference of between center grayscale value and the other eight pixel values respectively. While in Eq. (3), $l(x_c, y_c)$ denotes the center pixel values of the 3 × 3 window, and the other eight points are $g_0, \ldots, g_7$.

$$s(z)=\begin{cases}1, & z\geq 0\\ 0, & z<0\end{cases} \quad (2)$$

$$LBP(x_c, y_c)=\sum_{i=0}^{7} s(g_i, g_c)2^i \quad (3)$$

Fig 3 shows an example of LBP operator. Firstly, Fig 3(a) denotes the pixel values 3 × 3window, the gray value is 45 in the center pixel, eight adjacent pixel values are compared with the center pixel respectively. Then we can calculate the so threshold binary values Fig 3(b) according to Eq. (2), next in Fig 3(c), converting the binary number into a decimal number in a clockwise direction by Eq. (3). After scanning a fingerprint image using LBP operator, the LBP coding image of original image is obtained. Finally, the texture features of fingerprint image are calculated by the counting the fingerprint image histogram. We can calculate the LBP code of center pixel value. Fig 3(c), LBP code of the center pixel: $1\times 2^0+0\times 2^1+0\times 2^2+1\times 2^3+0\times 2^4+1\times 2^5+1\times 2^6+0\times 2^7=1+8+32+64=105$. Therefore, the local texture features of whole image can be described by histogram which is formed by 256 LBP codes.



(a) (b) (c)

Fig 3. An example of the LBP operator.

C. Support Vector Machine

Nowadays, classifier based on Support Vector Machine (SVM) [37] has arisen the interest of the research community, due to their simplicity. The SVM method (a supervised machine learning technique) is a useful technology for solving pattern recognition and regression analysis problems. The goal of SVM is to find the best hyper plane that divides the data into two different classes. LIBSVM software package [27, 28] which is a research of classification algorithm is the most commonly used tools. When we use SVM[28,38], two key issues need to be considered.

One problem is related to the selection of kernel function. According to the linear separable and linear inseparable, we can use different kernel functions. To make the samples classification easier and more accurate, the radial basis function (RBF) kernel makes nonlinearly mapping to a high-dimensional space. It notes that the class labels and features are all nonlinear. In our method, because of the advantages of a less complex model and less parameters, RBF kernel function is selected.

Another problem is about how to select appropriate kernel parameters. There are two parameters in the RBF kernel function: C and Υ .To find the best testing and training classification parameters, parameter optimization method is used. The executable file of parameter optimization method in LIBSVM is gunplot.exe. We can find the best pairs of classification parameter C and Υ by using the executable file, while the goal of the parameter optimization method is to obtain classification parameter pairs and predict the unknown data. Through the tool "Grid-search and Cross-validation", we can search the results of the optimal parameters.

IV. Experiment

In this section, the performance of our classification algorithm is estimated by using two official datasets: LivDet

2011 [5] and LivDet 2013 [29], which are the publicly available datasets provided in the Fingerprint Liveness Detection Competition. Firstly, we give a brief introduction about the two databases. Secondly, feature vectors classification is introduced using SVM classifier. Then, the validation criterion is applied which is used to describe the performance of our method. Finally, we also conduct experiments based on the Fingerprint Liveness Detection Competition LivDet2011and LivDet2013 databases, besides we compare our proposed method with the state-of-the art works.

A. Database Description

Since 2009, in order to verify the performance of the proposed state-of-the-art fingerprint liveness detection methods, the Department of Electrical and Computer Engineering of the Clarkon University (USA) and the Department of Electronic Engineering of the University of Cagliari(Italy) have held a LivDet Competition[5,29]. In our method, we decided to conduct experiments by using the datasets which are provided by the LivDet (Liveness Detection Competition)of 2011 [5] and 2013 [29]. And two LivDet sets were all divided into two parts: training set, which is used to train a classifier, and a testing set, used to estimate the performance of approach.

LivDet 2011 fingerprint images are composed of four different optical sensors (Biometrika FX2000 (500 dpi), Digital 4000B (500 dpi), Italdata ET10 (500 dpi), and Sagem MSO300 (500 dpi)). Half of datasets are trained and the others are tested using the SVM. Spoof fingerprints were captured by using four different materials, such as Sagem, ItlData, Biometrika and Digital Person.

TABLE I (a)
Table of the detailed information of LivDet2011

DATASET	LivDet2011			
Scanner	Biometrika	Dig.Pers	Italata	Sagem
Model No.	FX2000	400B	ET10	MSO300
Res.(dpi)	500	500	500	500
Image Size	315×372	355×391	640×480	352×384
Live Sample	1000	1000	1000	1000
Fake Sample	1000	1000	1000	1036

TABLE I (b)
Table of the detailed information of LivDet2013

DATASET	LivDet2013			
Scanner	Biometrika	Cmatch	Italata	Swipe
Model No.	FX200	V300LC	ET10	---
Res.(dpi)	569	500	500	96
Image Size	352×384	800×750	480×640	500×208
Live Sample	1001	1250	1000	1221
Fake Sample	1000	1000	2005	976

LivDet 2013 fingerprint images comprise four different flat optical sensors (a. Italdata ET10(500 dpi), b. CrossMatch Verifier 300LC (500 dpi), c. Biometrika FX2000 (569 dpi) and d. Swipe(96 dpi)), including 8775 real fingerprints and 8981 spoof fingerprints which were captured via using five different materials, such as Gelatin, Ecoflex, Latex, Modasil, and WoodGlue. Half of them are trained and the rest of fingerprints are tested using the SVM classifier.

Each dataset has been made in available to both academic and industrial instructions. More information is reported in TABLE I (a) and TABLE I (b) on the LivDets2011 and LiveDet2013. From the TABLE I (a) and TABLE I (b), we can clearly observe the difference of different LivDets. Some typical sample images of real and spoof fingerprints are presented in Fig 4 from different fingerprint sensors in LivDet 2011, and the ranges of fingerprint image size from 240 × 320 to 700 × 800. The material used is specified for the generation of the fake fingers, such as Silicone, Latex, Gelatin and Ecoflex. We can find that it is difficult to recognize the differences of spoofed fingertips just with our eyes.

B. The image Decomposition and Feature Extraction

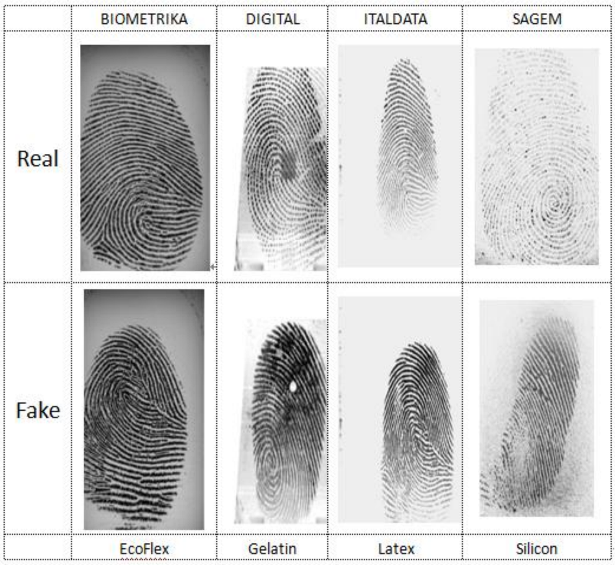


Fig 4. Typical sample images of real and spoof fingerprints those can be found in the LivDet 2011.

In this experiment, we are aim to decompose image and extract features through wavelet transform and LBP. For example, the size of the original image is 256 × 256. First of all, the fingerprint images are decomposed into four different coefficients after a layer of wavelet transform, which are Approximation coefficient, Horizontal coefficient, Vertical Coefficient and Diagonal coefficient respectively. The size of every coefficient is 128 × 128, which is one quarter of original image. The process of operation has been discussed in Part3. Between the four coefficients, the approximation coefficient which is represented by the symbol LL is similar to original image, however, the three different directions coefficients, which are represented by the symbol HL, LH and HH respectively, contain some high frequency information in the different directions. In our method, in order to compare and obtain the best combination of feature, four different coefficients combinations are constructed, which are $LL+HL+LH$, $LL+LH+HH$, $LL+HL+LH+HH$ *and* $LL+HL+HH$. Next, we calculate 256 LBP codes in each image by Eq. (2) and by Eq. (3). Since the LBP coding image includes local micro-mode information of the original image, the local features of the fingerprint image can be described through a histogram which is formed by 256 LBP codes in given images. Due to images have been decomposed into four different coefficients, feature vectors are constructed by calculate 256×4 texture features. Before construction of feature vectors, normalization is necessary due to unify data from different sensors to a reference frame as well as reduce the data scale is not unified the impact on the classification accuracy during SVM classifier. The main steps are as follows:

Step 1: Select training sets from LivDet 2011 and LivDet 2013 to form the model respectively.

Step 2: Select testing sets from LivDet 2011DB and LivDet 2013DB to test the efficiency of my method by using the constructed model classifier.

Step 3: For Images from Step 1 and Step 2, decompose image into four coefficients whose size is a quarter of original images. The four different coefficients are composed of one approximation coefficient and three detail coefficients, and we can denote the four coefficients by the symbol *LL* , *HL* , *LH* and *HH* respectively. According to coefficients, four different combinations can be constructed, which are *LL+HL+LH+HH*, *LL+HL+LH*, *LL+LH+HH* and *LL+HL+HH*.

Step 4: By obtaining four different combinations in Step 3, calculating their LBP codes for each combination, and the feature vector can be constructed by a histogram which is formed by 256 LBP codes. Before calculating LBP codes, normalization is necessary, which can simplify the calculation and reduce the quantity. Finally, 256 × 4 texture features are extracted in each image.

Step 5: Repeat Step 3 and Step 4 in LivDet 2011 DB and LivDet 2013 DB.

C. Performance Metrics and Classification Results

The Datasets derive from Fingerprint Liveness Detection Competition, and they are distributed through the website of the competition. We have discussed the detailed information of the LivDet 2011DB and LivDet 2013DB in Part IV. The performance of proposed approach is validated in the terms of the Average Classification Error (ACE), which is considered as standard metric for evaluation the LivDet competitions. It is defined as:

$$ACE = (FAR + FRR) / 2 , \qquad (4)$$

Where in equation (4),

$$FAR = \frac{Total\ Number\ Imposter\ Fingerprints\ Accepted\ as\ Genuine}{Total\ Number\ of\ Forgery\ Tests\ Performed}, \qquad (5)$$

$$FAR = \frac{Total\ Number\ Genuine\ Fingerprints\ Accepted\ as\ Imposter}{Total\ Number\ of\ Genuine\ Matching\ Tests\ Performed}, \qquad (6)$$

In the equation (4), where the False Accept Rate (FAR) represents the percentage of fake fingerprints being misclassified as real, and the False Reject Rate (FRR) computes the percentage of real fingerprints being assigned to the fake class. In our method, two successive processes are designed to obtain the unbiased classification accuracy in the process of the experiment, including training and testing processes:

Process 1: Training process. Aiming at constructing optimal texture features vectors, we propose a new method based on wavelet transform and LBP. First in our experiment, we can decompose the given fingerprint images into four different coefficients through a layer of wavelet transform. Second, four different combinations (*LL+HL+LH+HH*, *LL+HL+LH*, *LL+LH+HH* and *LL+HL+HH*) are constructed, which are defined Number 1, 2, 3 and 4 respectively. Then we calculate its LBP codes for each combination. Next, feature vector of each image is composed of 1024 parameters. Finally, classifier is built by using executable file svm-train.exe to train the obtained feature vectors in SVM. In order to make the results more accuracy, parameters optimization is a crucial step during the training process. Fig 5 presents the results of parameters optimization are for different sensors. For example, the same color describes the same accuracy. In Fig 5(a), the green lines present the highest classification accuracy when the value of parameter pair (C, Υ) is (8192, 0.5). And the classification accuracy is 99.8%. That is to say, we can obtain the best classification accuracy when we set parameter pair value in testing process. Similarity, the best accuracy responding to the Fig 5(b), (c), (d) can be found. If not, we require using several of different parameter pairs (C, Υ) to gain the best classification accuracy. Finally, the training model is built.

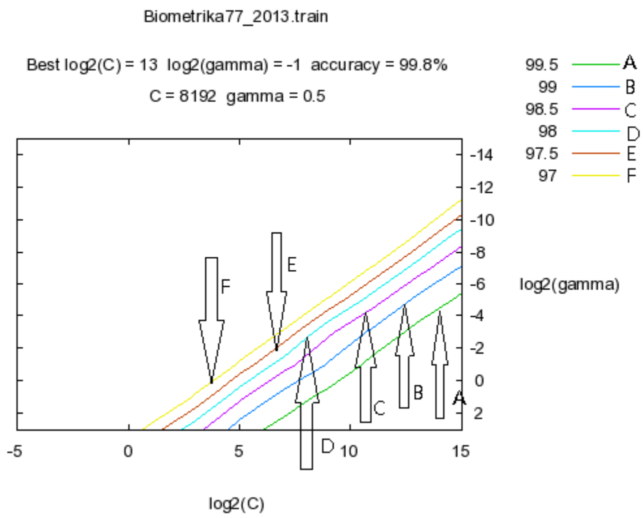


Fig. 5 (a). Results of the Parameter optimization based on Biometrika sensors in LivDet sensors in LivDet 2013.

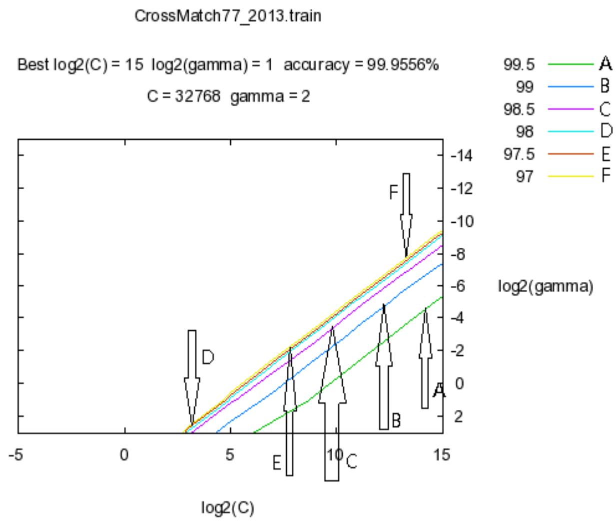


Fig. 5 (b). Results of the Parameter optimization based on CrossMatch sensors in LivDet sensors in LivDet 2013.

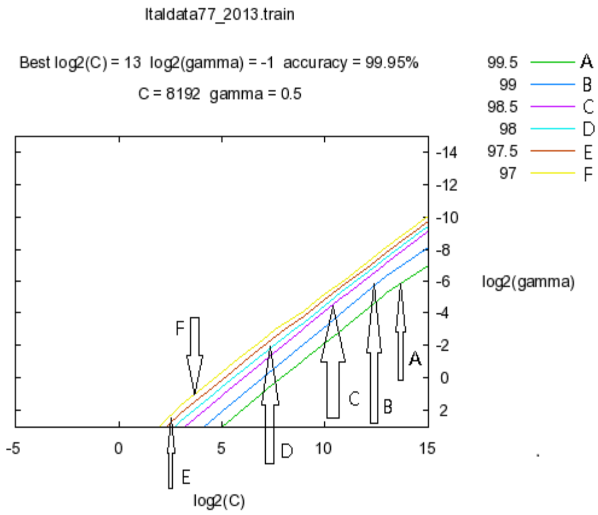


Fig. 5 (c). Results of the Parameter optimization based on Italdata sensors in LivDet sensors in LivDet 2013.

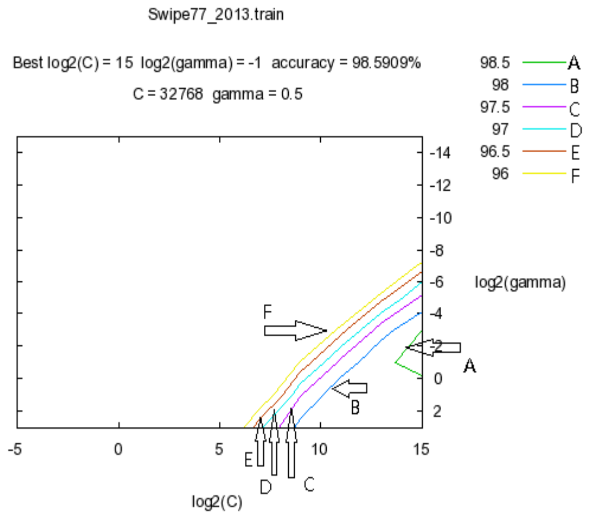


Fig. 5 (d). Results of the Parameter optimization based on Swipe sensors in LivDet sensors in LivDet 2013.

Process 2: Testing process. In our method, the features are extracted based on WT and LBP. Before constructing feature vectors, we need valid whether the images are gray images or not. If not, we need to change the given RGB images into gray images. The best feature vectors founded on the given training sets and testing sets are used to evaluate the performance of our proposed approach. The Testing and Training processes are measured on MATLAB R2010a. As mentioned before, we use the executable file grid.py tool to select the best parameter pair (C, Υ) as the parameter pair of validation of classification.

In our experiment, the Average Classification Error (ACE) detection accuracy and its comparison with the proposed methods for detecting fingerprint image vitality are shown in TABLE Ⅱ and TABLE Ⅲ. The accuracy of best designed algorithms from LivDet 2013 and the others' proposed method are shown in TABLE Ⅱ. It shows that our method achieve detection accuracy is superior to the best algorithm proposed in the LivDet2013. In order to facilitate the readers to observe, the best obtained values in TABLE Ⅱ and TABLE Ⅲ are highlighted in bold. It can be found that our method achieving average accuracy ACE (Average Classification Rate) is obviously superior to others' in LivDet 2013 DB and LivDet 2011DB. Fig 6 shows the classification error in different fingerprint sensors. The horizontal axis shows kind of sensors, and the vertical axis shows classification error. In Fig 6(a) and Fig 6(b), the combination of *LL+HL+LH+HH* is obviously superior to other combinations.

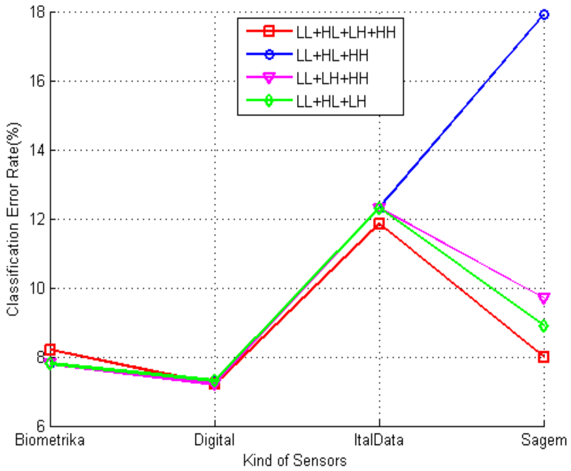


Fig 6 (a). Results of the classification Error based on the LivDet 2011DB.

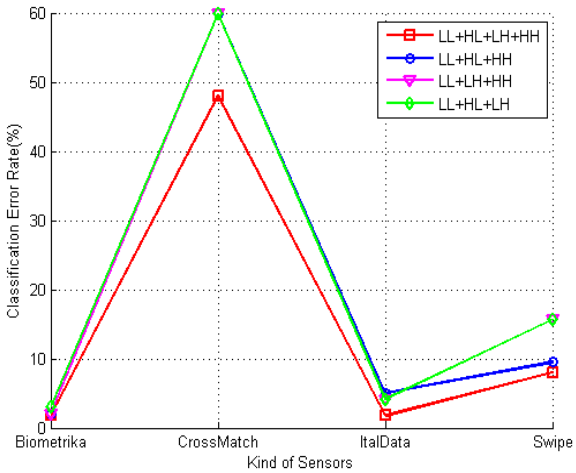


Fig 6 (b). Results of the classification Error based on the LivDet 2013DB.

TABLE Ⅱ
The results of the best different algorithms of LivDet 2013 in terms of average accuracy are cited from [29]

Methods	**The Average Classification Error ACE in (%)**				
	Bimometrika	**Cmatch**	**Italata**	**Swipe**	**Average**
Our method	**1.8**	48	**1.8**	8	**14.9**
Frassetto1[38]	4.55	**5.2**	47.65	5.97	15.84
Frassetto2 [38]	25.65	49.87	55.45	**4.02**	33.75
ATVS[29]	5.05	54.8	50	46.45	39.08
UniNap2[29]	6.55	52.13	9.45	26.85	23.75
Anonym3[29]	5.7	53.11	2.8	5.25	16.72
HZ-JLW[29]	32.95	55.56	13.15	15.19	29.21

TABLE III
The comparison in terms of ACE in database of the LivDet 2011

Methods	The Average Classification Error ACE in (%)				
	Bimometrika	**Digital**	**Italata**	**Sagem**	**Average**
Our method	8.2	7.2	**11.85**	7.86	**8.78**
Original LBP [31]	13	10.8	24.1	11.5	14.85
Power Spectrum [32]	30.6	27.1	42.8	31.5	33
Dermalog [5]	20	36.1	21.8	13.8	22.93
Federico [5]	40	8.9	40	13.4	25.57
LPB PCA SVM[30]	8.2	3.85	23.68	5.56	10.32
Jia's method [34]	10	**7.1**	16.3	**6.1**	9.95
OCSNE [35]	**3.2**	33.6	15.2	16.1	17.025
Curvelet energy [33]	45.2	21.9	47.9	28.5	35.88
Best Result in LivDet2011[5]	20	36.1	21.8	13.8	22.93

V. CONCLUSION

A novel fingerprint livness detection approach based on wavelet transform and LBP codes has been proposed. The constructed feature vectors have been tested on publicly available databases, which are the database used in the 2011 LivDet competition [5], and a database released in the 2013 LivDet competition [29]. After the features obtained are trained by the SVM executable file train.exe, we can get a SVM model classifier. With the help of the trained model, we can predict the test dataset classifier accuracy via using the predict method of libSVM. The experimental result shown by the proposed system under these completely diverse testing scenarios, correctly classifying almost 92% of the fingerprint images, proves its ability to adapt to all types of attacks and its efficiency as a method to minimize their effect and enhance the general security of fingerprint verification systems. Furthermore, The proposed approach is part of the software-based solutions as it distinguishes the real or fake fingers only based on the acquired sample, and not on other physiological measures (e.g., odor, heartbeat, skin impedance) captured by special hardware devices added to the sensor (i.e., hardware-based solutions that increase the cost of the sensors, and are more intrusive to the user). Liveness detection solutions such as the one presented in this work are of great importance in the biometric field as they help to prevent direct attacks and meanwhile enhance the security of systems.

The classification accuracy of samples is extremely affected by the noise during the classification phase. When we consider the noise of image, the tested accuracy is unsatisfactory. Yet, we can lower the influence of different noise through introducing noise filters with idea from Jin et al [30]. Besides, we will also construct feature vectors to detect the vitality of fingerprint through two layer wavelet transform or more layer of wavelet transform. These will be done in our future works.

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