Liveness Detection on Touchless Fingerprint Scanner

**Katerina Fortova**

Faculty of Information Technology, Brno University of Technology  
Bozetechova 2, Brno, Czech Republic

xforto00@vutbr.cz

***Abstract* -** This paper presents suitable method for fingerprint liveness detection under different wavelengths using various algorithms. Liveness detection is an anti-spoofing method which can detect physiological signs of life from fingerprints to ensure only live fingers can be captured for enrolment or authentication. The major challenge is to extract texture features from fingerprint based on Local Binary Pattern, Sobel and Laplacian operator and Wavelet transform. For this paper, touchless scanner with special lighting conditions was used to capture real and fake fingerprints obtaining 216 images. Firstly, the dataset was divided into three categories of wavelengths - red, blue and green. To estimate the performance of the methods several analyses of wavelengths and classification were done on a specific wavelength each time. Then the whole dataset, containing of all images with different illuminations, was tested again to measure the accuracy rate. Artificial Neural Networks, Support Vector Machines and Decision Trees were used for classification during these experiments. Experimental results indicate that the proposed approach achieved the best accuracy 90.1% for the red light images. Then all used techniques were compared. Classification with vector based on Local Binary Pattern achieved average accuracy 89.8%. Average accuracy of liveness detection with vector based on Sobel and Laplacian operator was 91.5%. Classification with vector based on Wavelet transform achieved average accuracy 84.8%. Several wavelet families were used for classification with this vector. Wavelets of Biorthogonal family achieved average accuracy 85.1%, wavelets of Reverse Biorthogonal family reached accuracy 86.6%.

***Keywords*:** liveness detection, image processing, touchless fingerprint scanner, biometrics

**1. Introduction**

The matter of data security is becoming more actual during technology and intelligent devices development. Data protection with biometrical attributes such as fingerprint or face is nowadays widely used. People don’t have to remember long passwords and access to various systems and devices become easier. However, also these systems can be attacked. Spoofed fingerprints can be made from many broadly available artificial materials. Therefore, it is important to find some algorithms for liveness detection of fingerprint, which can detect the fake samples.

We can use two types of fingerprint scanners for taking images – traditional touch-based scanners and touchless scanners. Fingerprint does not come in contact with any surface during using of touchless scanner. Using of touch-based scanners could be also unhygienic especially in crowded places and users have to put pressure on the surface, because skin of the fingerprint isn’t flat unlike the surface. The result of image can be distorted. [1]

This paper is organized as follows – after brief introduction in this Section 1, Section 2 contains description of touchless scanner and gaining the dataset. Section 3 contains information about related works. Section 4 presents pre-processing techniques for fingerprints, Local Binary Pattern, Sobel and Laplacian operator, Wavelet transform and Gray Level Co-occurrence Matrix. Proposed method can be found in Section 5 with description of extracted vectors and results of experiments. Section 6 is focused on conclusion of work.

**2. Touchless scanner and gaining of dataset**

Used touchless scanner contains three cameras – one central and two on sides of scanner. Only central camera was used for research because of best image quality. Three LED lights with blue, green and red color illuminated gained fingerprints. Some experiments with ultraviolet light were also made, but the light was weak, and results weren’t good, therefore this light wasn’t used in this work.

Live fingerprints were gained from approximately six people. Afterwards about 36 samples of fake fingerprints were used for our dataset. It was necessary to prevent very bright images without apparent papillary lines. Dataset contains 216 images with using three light colors – 108 images of live fingerprints and 108 images of fake fingerprints.

**3. Related work**

Many approaches were created for fingerprint liveness detection. However, majority of them is focused on classic touch-based scanners and not touchless scanners because it is the latest generation of fingerprint sensor technology. Caue Zaghetto, Mateus Mendelson, Alexandre Zaghetto and Flavio de B. Vidal introduced approach for liveness detection on touchless device with using texture descriptors and artificial neural networks (ANN). Feature vector was composed from 512 descriptors of Improved Local Binary Pattern (ILBP) and 4 descriptors of Grey Level Cooccurrence Matrix (GLCM) (contrast, correlation, energy and homogeneity). 8 GLCM matrices were calculated for each direction determined by the current analyzed pixel and the final 4 descriptors were the average of these 8 matrices. Then Principal Component Analysis was applied to this vector and ANN was used for classification for decision between real and fake fingerprint and also for prediction of artificial material of fake fingerprint. [2] Drahansky, Dolezel, Vana, Brezinova, Yim and Shim announced novel approach of measurement of optical characteristics in the finger based on pressure change. They worked with two characteristics of live human fingers – change of color and elasticity due to pressing of finger against glass plate. Their next proposed method was focused on optical changes in the finger based on illuminations with various wavelengths. This approach did not need to work with the glass plate as the previous work. The finger was illuminated with red, green and blue color, then only pixels from fixed rectangle were extracted from image and images of all three light color were merged. The global features extracted from the fixed rectangle were pixel intensity arithmetic mean, pixel intensity standard deviation, pixel intensity median, histogram mean, histogram standard deviation and histogram median. The experiments with several color models were realized. ANN and random forests were used for classification. [3]

**4. Algorithms used for pre-processing and liveness detection**

This section contains description of used algorithms for pre-processing and liveness detection. More techniques for extraction of vectors for classification were chosen. The goal was to compare several approaches for liveness detection and their accuracies.

**4.1. Image pre-processing – normalization, thresholding and segmentation**

The image is loaded in grey scale and then the normalization is used. Normalization is a process, when the range of intensity values of pixels is adjusted. The goal is to raise dynamic range of grey scale brightness and minimize changes of grey scale values along ridges and valleys of fingerprints.

Three methods for thresholding were used. Otsu method uses thresh, which is constant and based on particular image. Gaussian and Mean methods for thresholding are adaptive algorithms. The value of thresh is not constant along whole image, but changes for every pixel. These methods are suitable for images with different light conditions or with images containing shadows. The value of thresh for Adaptive Mean Thresholding is mean of pixel neighbors, for Adaptive Gaussian Thresholding the thresh value is a weighted sum of neighbor pixels, where the weights are Gaussian window. [4]

Obsah obrázku zvíře

Popis byl vytvořen automatickyObsah obrázku ryba

Popis byl vytvořen automatickyObsah obrázku kreslení

Popis byl vytvořen automaticky

Fig. 1: Thresholding using Otsu method. Fig. 2: Thresholding using Gaussian method. Fig. 3: Thresholding using Mean method.

Morphological operations such as erosion and dilation are used for image segmentation. The mask of segmented fingerprint is extracted. Result of segmentation is segmented fingerprint on white background.

**4.2. Local Binary Pattern**

Local Binary Pattern (LBP) is algorithm, which is widely used for analysis of image texture. LBP is suitable for gaining information about changes of intensity along image pixels and their neighbours. The equation for computing LBP is represented below, are values of neighbour pixels, is value of central pixel and is index of neighbour.

(1)

The description of method is as follows: The window pixels is established, where our central pixel is a centre with eight neighbours. The new value for every neighbour pixel is computed based on this rule: If the value of neighbour pixel is greater or equal to value of central pixel, the new value of neighbour pixel is 1, otherwise 0. After the computation of neighbour pixels, the new value for central pixel is computed. [5]

Obsah obrázku fotka, staré, muž, telefon

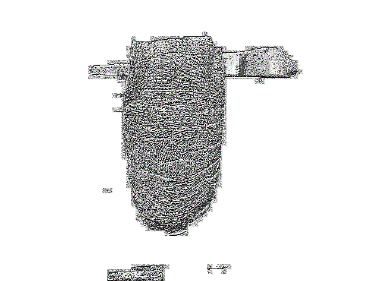
Popis byl vytvořen automaticky

Fig. 1: Live fingerprint processed by LBP. Fig. 2: Fake fingerprint processed by LBP.

**4.3. Sobel and Laplacian Edge Detectors**

Sobel and Laplacian operators are good solution for detecting edges in image and texture description. They reduce the amount of data, pixels, for analysis and highlight structural aspect of input image.Sobel operator is a method based on gradient, the first derivatives are computed for image along and axis. Therefore, we get two results after the application of Sobel operator. Result for Laplacian operator is only one, because this method uses only one kernel. [6]

Obsah obrázku černá, tmavé, bílá, muž

Popis byl vytvořen automatickyObsah obrázku tmavé, bílá, černá, voda

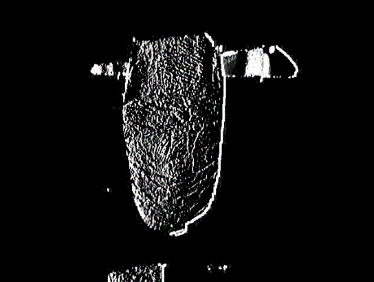
Popis byl vytvořen automaticky

Fig. 8: Sobel of x axis for fingerprint. Fig. 9: Sobel of y axis for fingerprint. Fig. 10: Fingerprint processed by Laplacian operator.

**4.4. Wavelet transform**

Wavelet transform is next method used for liveness detection in this research. Wavelet transform is group of transformations, which differ according to base function – wavelet. Each wavelet is based on mother wavelet from wavelet family. Wavelet transform belongs to group of linear transforms. This method can be used for image compression or noise filtering.

Mother wavelet Ψ determines the wavelet shape. Father wavelet Φ gives function determining scale. Related wavelets are called daughter wavelets, they are marked as , where is scale and is shift of wavelet function. [7]

The equation of Continuous Wavelet Transform (CWT) is represented below: [8]

(2)

Signal is correlated with wavelets related to mother wavelet. Symbol \* represents complex conjugate. The result is , where represents scaling parameter and position. The constant is used for normalization of energy of wavelet during scale changes.

Discrete Wavelet Transform (DWT) does not need lots of coefficients unlike CWT. Only coefficients with scale are used. For parameters stands:

(3)

(4)

The final equation of DWT is stated below:

(5)

DWT is used in image processing for edge and texture detection, compression, noise filtering or getting important features used for next classification. [7] The properties for wavelets are symmetry, asymmetry, orthogonality and biorthogonality. [9] Three wavelet families of DWT were used for this research.

Daubechies Wavelets are asymmetric, orthogonal and biorthogonal wavelets. [9] They are marked as db*A*, where *A* is parameter for count of vanishing moments. We can use db1 to db20 for our analysis, db1 to db10 are commonly used. They use same parameters for filters for decomposition and reconstruction. [7] Vanishing moment represents wavelet ability of polynomial behaviour in signal. For example, db1 with one vanishing moment easily encodes constant signal components, db2 encodes constant and linear signal components and db3 encodes constant, linear and quadratic signal components. [10] Biorthogonal spline wavelets (also called Cohen-Daubechies-Feauveau Wavelets) are symmetric, biorthogonal and not orthogonal. [9] They differ with shape and properties from Daubechies wavelets, but the construction of wavelets is the same. B-spline is used for generating these wavelets. [11] They are used in JPEG 2000 compression standard and for compression of fingerprints for FBI. Reverse biorthogonal spline wavelets are symmetric, biorthogonal and not orthogonal. [9] They were used in previous research for iris detection. [12]

**4.5.** **Grey Level Cooccurrence Matrix (GLCM)**

Grey Level Cooccurrence Matrix (GLCM) was used for extracting important features for processed images. GLCM is represented as square matrix. Elements on coordinates represent occurrences count when two adjacent pixels have values and in our original image. Normalized GLCM matrix has count of grey levels in image. Parameters and describe mean and parameters and describe standard deviation. [2]

For important characteristics were extracted from 14 characteristics of GLCM – contrast, correlation, energy and homogeneity. Contrast and correlation are calculated as follows: [13]

(6)

(7)

Property ASM (Angular Second Moment) is closely connected with energy. These are equations for ASM and energy: [13]

(8)

(9)

Homogeneity is last important extracted feature from GLCM matrix. It is calculated as follows: [13]

(10)

**4. Proposed Method Description**

This section contains description of proposed method for liveness detection on touchless fingerprint scanner. The goal was to extract several vectors based on LBP, Sobel and Laplacian operator and Wavelet transform. Each image was pre-processed with techniques mentioned in subsection 4.1.

**4.1. Extracted vectors from image**

Three different vectors were used for research - vector based on Local Binary Pattern, Sobel and Laplacian operator and Wavelet transform. The important feature for every vector was Gray Level Cooccurrence Matrix (GLCM), which works as a classifier of texture in image. Values of contrast, correlation, energy and homogeneity were extracted from GLCM.

Extracted vector based on LBP is focused on image processed by LBP and extraction of features from GLCM based on pre-processed grey level image. The histogram is extracted from LBP image and contains 256 bins and their pixel count values . Four partial sums of this LBP histogram were extracted:

(11)

(12)

(13)

(14)

The extracted vector contains these four partial sums of LBP histogram and features of input grey scale pre-processed image – contrast , homogeneity , energy and correlation .

Vector based on Sobel and Laplacian operator contains contrast , homogeneity , energy and correlation features from GLCM matrix. These values are computed for result of processing fingerprint with Sobel operator on x-axis , result of Sobel operator on y-axis and result of processing fingerprint with Laplacian operator .

Last extracted vector was based on Wavelet transform. Four same features from GLCM matrix were extracted for three results gained after processing fingerprint with Wavelet transform – horizontal result , vertical result and diagonal result .

**4.2. Analyse of images illuminated with same light**

Dataset was divided into three smaller ones according to the colour of illuminated light for this first experiment. The goal was to decide according to the highest average accuracy of prediction about best classification algorithm, best thresholding method used during pre-processing, best type of extracted feature vector and finally best wavelength of illuminated light. Classification method (artificial neural network (ANN), support vector machines (SVM) and decision trees (DTs)) was trained with the same ratio of live fingerprints and fake fingerprints. The result of liveness detection for tested fingerprints was predicted. These classification methods can be compared based on their best average accuracy of prediction for liveness detection:

Table 1: Average accuracy of various classification methods.

|  |  |
| --- | --- |
| **Classification method** | **Average accuracy of classification [%]** |
| ANN | 90.131 |
| SVM | 84.392 |
| DTs | 82.983 |

Three thresholding algorithms were used for fingerprint pre-processing. Fingerprints pre-processed with using Otsu thresholding achieved the highest accuracy compared to adaptive thresholding methods – Mean and Gaussian.

Table 2: Average accuracy with using several thresholding algorithms during pre-processing.

|  |  |
| --- | --- |
| **Used thresholding** | **Average accuracy of classification [%]** |
| Otsu | 88.574 |
| Mean | 85.882 |
| Gaussian | 82.418 |

Average accuracies of liveness detection with three different vectors were compared. Vector based on Wavelet transform used several different wavelets. Wavelet rbio3.1 of Reverse biorthogonal spline family showed best results for liveness detection (86.3%). The best tested wavelet of Biorthogonal spline wavelet family was bior1.3 with average accuracy 85.3%. On the other hand, tested Daubechies wavelets achieved the lowest accuracy compared to wavelets of Biorthogonal spline wavelet family and Reverse biorthogonal spline wavelet family.

Table 3: Average accuracy of used wavelets for first experiment.

|  |  |
| --- | --- |
| **Wavelet type** | **Average accuracy of classification [%]** |
| rbio3.1 | 86.258 |
| bior1.3 | 85.303 |
| bior1.5 | 85.146 |
| db4 | 84.994 |
| bior2.4 | 84.411 |
| db2 | 83.064 |

All three extracted vectors can be compared. The value for accuracy of Wavelet transform is mean of all used types of wavelets during experiment. Vectors based on Sobel and Laplacian operator and LBP achieved best accuracies for this experiment, they both have average accuracy of classification about 90%.

Table 4: Average accuracy of used extracted vectors for first experiment.

|  |  |
| --- | --- |
| **Type of extracted vector** | **Average accuracy of classification [%]** |
| Sobel and Laplacian operator | 90.256 |
| LBP | 90.197 |
| Wavelet transform | 84.863 |

We can compare all three lights of different wavelength in the end of this experiment. It was discovered that the best accuracy showed fingerprints which were illuminated by red light.

Table 5: Comparison of different wavelengths for liveness detection.

|  |  |
| --- | --- |
| **Used colour of illuminated light** | **Average accuracy of classification [%]** |
| Red | 90.067 |
| Blue | 86.756 |
| Green | 80.682 |

**4.2. Analyse of whole dataset**

Whole dataset of 216 samples illuminated by various lights (green, blue and red) was used for second experiment. Classification method was trained with same ratio of live samples and fake samples as during previous experiment. The goal was to decide about most accurate classification technique, thresholding algorithm for segmentation and extracted vectors again.

The order of classification methods and thresholding techniques is the same as in previous experiment. Average accuracy for ANN is 88.8%, SVM reached 85.0% and DTs achieved the accuracy of 83.6%. Average accuracies for Otsu, Mean and Gaussian thresholding during pre-processing are 87.7%, 85.3% and 83.3% in the order given. Nevertheless, order of best wavelets for vector based on Wavelet transform is slightly different.

Table 6: Average accuracy of used wavelets for second experiment.

|  |  |
| --- | --- |
| **Wavelet type** | **Average accuracy of classification [%]** |
| rbio3.1 | 86.895 |
| bior1.3 | 86.325 |
| bior2.4 | 85.185 |
| db4 | 84.615 |
| bior1.5 | 84.188 |
| db2 | 81.766 |

All vectors were compared again. The results are very similar to previous experiment. Vector based on Sobel and Laplacian operator is still the extracted feature vector, which gave most accurate results. Vector based on LBP achieved average accuracy 89.3%. Third vector, which uses Wavelet transform, reached accuracy about 84.8%. It is the least accurate extracted vector for our experiment. On the other hand, Wavelet transform is suitable for making experiments with wide range of wavelets of various Wavelet families.

Table 7: Average accuracy of used extracted vectors for second experiment.

|  |  |
| --- | --- |
| **Type of extracted vector** | **Average accuracy of classification [%]** |
| Sobel and Laplacian operator | 92.735 |
| LBP | 89.316 |
| Wavelet transform | 84.829 |

**5. Conclusion**

This paper introduced method for liveness detection on touchless scanner. Dataset containing 216 images of live and fake samples was gained with using touchless scanner and illumination of fingerprint by light of various wavelengths – green, blue and red colour. Three types of vector used for liveness detection were extracted from fingerprints – vector based on LBP, Sobel and Laplacian operator and Wavelet transform. The goal was to find best classification technique, best thresholding used during pre-processing and best extracted vectors based on average accuracy during both experiments. First experiment worked with separated images illuminated by same wavelength. Fingerprints illuminated with red light, which has the highest value of wavelength, were most suitable for liveness detection. Whole gained dataset was used for second experiment. Overall, the most accurate method for classification was ANN with average accuracy 89.4% and the most accurate thresholding for pre-processing was Otsu algorithm with average accuracy 88.2%. Vectors based on Sobel and Laplacian operator and LBP achieved accuracy of liveness detection about 90% during both experiments. Vector based on Wavelet transform reached accuracy about 85%. The amount of works focused on liveness detection on touchless devices is lower compared to techniques of liveness detection on touch-based devices. The goal of research was to introduced approach with using several texture algorithms and compare gained results. Future work may include expansion of dataset gained with touchless fingerprint scanner.

**References**

|  |  |
| --- | --- |
| [1] | C. Lee, S. Lee and J. Kim, "A Study of Touchless Fingerprint Recognition System," *Structural, Syntactic, and Statistical Pattern Recognition - Joint IAPR International Workshops, SSPR 2006 and SPR 2006, Hong Kong, China, August 17-19, 2006,* pp. 358-365, August 2006. |
| [2] | C. Zaghetto, M. Mendelson, A. Zaghetto and F. d. B. Vidal, "Liveness Detection on Touchless Fingerprint Devices Using Texture Descriptors and Artificial Neural Networks," *2017 IEEE International Joint Conference on Biometrics (IJCB),* pp. 406-412, October 2017. |
| [3] | M. Drahansky, M. Dolezel, J. Vana, E. Brezinova, J. Yim and K. Shim, "New Optical Methods for Liveness Detection on Fingers," *BioMed Research International - Biometrics and Biosecurity 2013,* vol. 2013, pp. 74-84, 2013. |
| [4] | OpenCV, "Image Thresholding," 2020. [Online]. Available: https://docs.opencv.org/3.4/d7/d4d/tutorial\_py\_thresholding.html. [Accessed 3 March 2020]. |
| [5] | A. Gaikwad, "Evaluation of Fingerprint Identification Based on Local Binary Pattern (LBP)," *International Journal for Research in Engineering Application & Management (IJREAM),* vol. 4, no. 4, p. 395–400, 2018. |
| [6] | U. Sinha, "The Sobel and Laplacian Edge Detectors," 2017. [Online]. Available: https://www.aishack.in/tutorials/sobel-laplacian-edge-detectors/. [Accessed 11 March 2020]. |
| [7] | V. Hlavac, "Vlnkova transformace," 2015. [Online]. Available: http://people.ciirc.cvut.cz/~hlavac/TeachPresCz/11DigZprObr/14WaveletsCz.pdf. [Accessed 4 March 2020]. |
| [8] | E. Anisimova, J. Bednar and P. Pata, "Image processing using the wavelet transform," *Elektrorevue,* vol. 15, no. 4, pp. 238-246, 2013. |
| [9] | PyWavelets, "Wavelet Properties Browser," 2020. [Online]. Available: http://wavelets.pybytes.com/. [Accessed 15 March 2020]. |
| [10] | A. Bultheel and D. Huybrechs, "Wavelets with applications in signal," August 2014. [Online]. Available: https://people.cs.kuleuven.be/~daan.huybrechs/teaching/wavelets2014.pdf. [Accessed 5 March 2020]. |
| [11] | C. Vonesch, T. Blu and M. Unser, "Generalized biorthogonal Daubechies wavelets," *Proceedings Volume 5914, Wavelets XI,* 2005. |
| [12] | R. Szewczyk, K. Grabowski, M. Napieralska, W. Sankowski, M. Zubert and A. Napieralski, "A reliable iris recognition algorithm based on reverse biorthogonal wavelet transform," *Pattern Recognition Letters,* vol. 33, no. 8, pp. 1019-1026, 2012. |
| [13] | Skimage, "Module: feature.texture - greycomatrix," 2011. [Online]. Available: https://scikit-image.org/docs/0.7.0/api/skimage.feature.texture.html. [Accessed 17 February 2020]. |