Biometric Image Recognition Based on Optical Correlator

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Abstract. *The aim of this paper is to design a biometric images recognition system able to recognize biometric images-eye and DNA marker. The input scenes are processed by user-friendly software created in C# programming language and then are compared with reference images stored in database. In this system, Cambridge optical correlator is used as an image comparator based on similarity of images in the recognition phase.*

Keywords

Biometrical images, Cambridge optical correlator, JTC, MF, optical Fourier transform, recognition.

1. Introduction

Nowadays, identification of individual person based on biometrics ispopular research field. For example, it helps to tackle various criminal activity, to obtain related information about origin of the person and it is possible to use it almost anywhere. In order to identify someone, it is necessary to store the information about biometric features into a specific database. Such databases are among the most extensive databases of the world. They contain a huge amount of information that must be processed as quickly as possible. There are many ways and algorithms for faster and also more reliable searching. One way is the optical data processing.

At present, biometrics is an area that is developing rapidly. The development also involves greater demands on information processing speed and fast growing database size. Optical correlator has the potential to quickly search in these huge databases. The biometrics database is an example of such massive analysis databases of DNA data. Every individual has different DNA structure and thus different genes. Each of these genes may affect the health of an individual. This means that the presence or absence of a gene strongly influences the onset of the disease. It is necessary to search for a relationship between a gene and expression of phenotypes. The discovery of such associations is a complex process that passes through billions of database elements in thousands of iterations and it's expensive for electronic computers. A potential solution is optical correlator, which is appropriate in the biomedicine not only for finding a DNA data, but also in identification of fingerprints and facial features. The advantage of biometric facial features, unlike other methods of identifying people is their universality, uniqueness and by their comparison the individual can be clearly identified.

The aim of this paper is to explore the application of optical correlator for biometric image recognition. Specifically, it deals with the design of eye recognition system based on the iris of the eye and also design of DNA markers recognition system. Designed user-friendly software for image pre-processing and Cambridge optical Correlator (CC) are parts of these systems, which can recognize the image based on their similarity.

In Sec. 2. , the theoretical principles of optical data processing are described. Section 3. contains a basic description of the optical correlator and distribution of its components based on the method of processing information. The proposed systems for biometrical images recognition - eyes and DNA markers, are involved in Sec. 4. Experiments and results are presented in Sec. 5. and conclusion is summarized in Sec. 6.

2. Fourier Optics

The Fourier Transform (FT) is used for the analysis and processing of digital images and enables image description in other variables via integral transformation. Therefore, it can be used for various purposes, such as detection of edges or image compression. This method can also provide information about the location of edges in images, colour scheme and image through frequency and amplitude spectrum receiving assistance FT [1] and [2].

2.1. Introduction to Fourier Optics

Fourier optics provides a description of the propagation of light waves based on harmonic analysis and linear systems. Harmonic analysis is based on the expansion of an arbitrary function of time as a sum of harmonic functions of time with different frequencies and different amplitudes:

$$f(t) = \int_{-\infty}^{+\infty} \tilde{f}(v)\exp(-j2\pi vt)\mathrm{d}v, \tag{1}$$

where the function $\tilde{f}(v)\exp(-j2\pi vt)$ is a harmonic function with frequency v and complex amplitude $\tilde{f}(v)$.

This approach is useful for the description of linear systems. If the response of the system to each harmonic function is known, the response to an arbitrary input function can be determined. The response of a linear system can be therefore determined by using harmonic analysis at the input and superposition at the output. Consider now an arbitrary function $f(x, y)$ of the two variables x and y. We suppose that x and y represent the spatial coordinates in a plane, $f(x, y)$ can also be written as a sum of harmonic functions of x and y:

$$\begin{aligned} &f(x, y) = \\ &= \int\int \tilde{f}(v_x, v_y)\exp\left[-j2\pi(v_x x + v_y x)\right]\mathrm{d}v_x\mathrm{d}v_y, \end{aligned} \tag{2}$$

where $\tilde{f}(v_x, v_y)$ is the complex amplitude of the harmonic functions, v_x and v_y are the spatial frequencies in the x and y directions, respectively [1] and [3].

2.2. Optical Fourier Transform Implementation

One of the Fourier optics properties is that the lens produces amplitude distribution of light at its back focal plane. This distribution is proportional to the FT amplitude in a plane with the displayed object(object plane).

Special case, advantageous for the study of the optical FT and the spatial filtering, is a two-lens system (Fig. 1). According to Fourier optics, such system constitutes a cascade of two subsystems implementing the FT. The first subsystem creates a direct FT in the focal plane of the first lens (also called the Fourier plane). A second subsystem (between the Fourier plane and the focal plane of the system) performs inverse FT and we can immediately deduce the inter changeability of running light beams. The result is a picture that is an exact replica of the object.

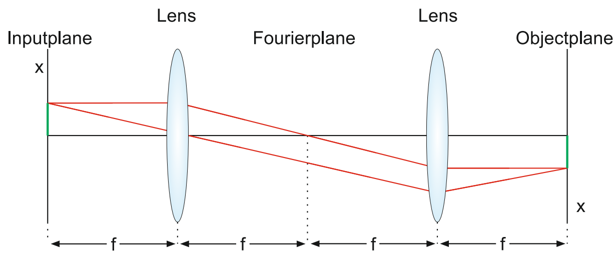


Fig. 1: 4-f two lens system.

This two-lens imaging system is called 4-f system or coherent optical processor. Its use as a spatial filter is clearly shown in the case, where the amplitude of the light wave $f(x, y)$ is a function of two variables, see Fig. 2. As follows from the above analogy - every "point" in the Fourier plane corresponds to one spatial frequency. Put in a Fourier plane suitable mask (i.e., impervious shield having a defined spaced slot = filter), which will block some spatial frequencies andleak others. We get in the image plane an image with an amplitude $F(x, y)$ which is a filtered version of the subject of the amplitude $f(x, y)$. This optical spatial frequency filtering can selectively suppress or completely eliminate some geometric features of the image, change the contrast etc. [1], [3] and [4].

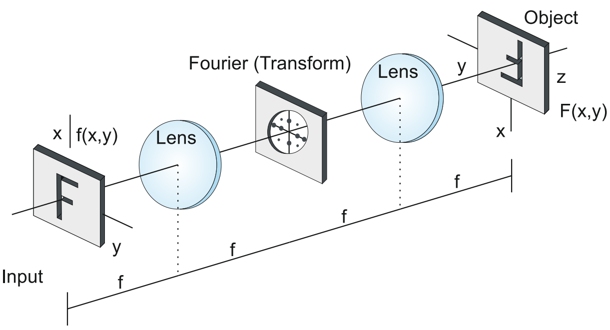


Fig. 2: 4-f system configuration for implementing the optical Fourier transform.

3. Optical Correlator

Optical correlator is a device executing comprehensive comparison with high speed. Optical correlator takes advantage of Fourier and Hilbert transforms. There are several types of correlators that achieve comparable results despite the fact that their information processing is different in each of these types. In general, the Optical correlators are divided into two basic types according to method of processing information - Optical correlators using Matched Filter (MF), and Optical correlators using Joint Transformation (JTC) [5].

3.1. Matched Filter

The basis of MF is Vanderlugt's filter which was invented by A. Vanderlugt in 1964. The MF is currently regarded as the most frequently used correlator. Its architecture is based on a 4-f systemdescribed above (Fig. 2).

The correlation of this type of correlator consists of two independent correlations. The first is the correlation of the input image $s(x, y)$, and the second is correlation of the reference image $r(x, y)$. Input scene is shown on Spatial Light Modulator (SLM). Then this scene undergoes FT. Reference image is used to create Matched filter which is applied as reference filter. After that, input scene is multiplied by reference filter. Finally, product of multiplication undergoes FT which produces plane with correlation peaks. The process of correlation is shown in Fig. 3.

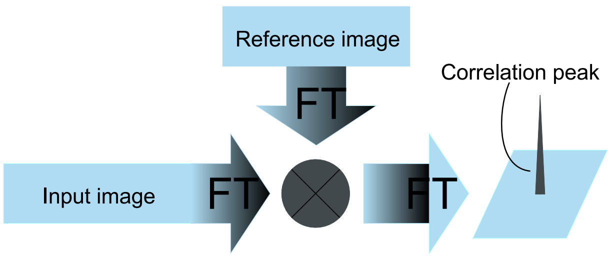


Fig. 3: Principle of Match Filter correlator.

Mathematical expression of this correlation can be written as follows:

$$s \oplus r = c(x, y) = F\left\{S(\alpha, \beta)R^*(\alpha, \beta)\right\}, \tag{3}$$

where $s \oplus r$ represents correlation between input and reference image, and F is FT. $S(\alpha, \beta)$ is FT of input image and $R^*(\alpha, \beta)$ is complex conjugate function of $R(\alpha, \beta)$.

The advantages of this method are high space - bandwidth product and extremely fast process time, but disadvantage is the need to create reference filter, Matched filter from reference image, so also reference image is neededforstart of the correlation process [5] and [6].

3.2. Joint Transform Correlator

JTC was invented in 1966 by Weaver and Goodman. The principle of the correlator based on the fact that reference filter is not required before starting correlation is shown in the Fig. 4. It can be seen that JTC has an input and reference image aligned and displayed together on the SLM. Subsequently, these images are transformed by Fourier transformation and a non-linear camera then captures the intensity distribution of transform to produce Joint Power Spectrum (JPS).

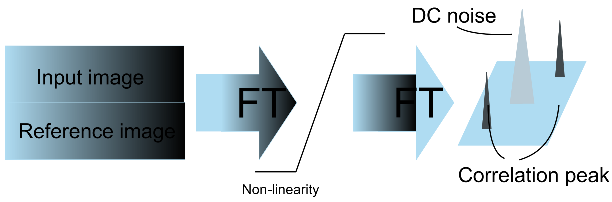


Fig. 4: Principle of Joint Transform Correlator.

JPS is binary or threshold processed and this processed image enters to transform process as input image of second FT. Output of this transform is the correlation plane that includes correlation peaks per match. Found matches are shown as highly localized intensities. Peak intensities provide a measure of similarity of compared images. Positions of peaks denote relative align of the images in the input scene.

Mathematical expression of the input scene can be written as follows:

$$f(x, y) = s(x, y) + r(x, y), \tag{4}$$

where $s(x, y)$ and $r(x, y)$ represents input and reference images shown in input plane. The input scene $f(x, y)$ is then transformed by FT and produces $F(\alpha, \beta)$.

$$\begin{aligned} F(\alpha, \beta) &= F\left\{s(x, y)\right\} + F\left\{r(x, y)\right\} = \\ &= S(\alpha, \beta) + R(\alpha, \beta). \end{aligned} \tag{5}$$

Using next equations, the square of absolute value of transformed input scene can be produced.

$$\begin{aligned} J(\alpha, \beta) &= \left|F(\alpha, \beta)\right|^2 = \left|S(\alpha, \beta) + R(\alpha, \beta)\right|^2 = \\ &= \left|S(\alpha, \beta)\right|^2 + \left|R(\alpha, \beta)\right|^2 + 2\left|S(\alpha, \beta) \cdot R(\alpha, \beta)\right|. \end{aligned} \tag{6}$$

The square of absolute value of complex function is equal to multiplication of function with its complex conjugated function and then we can write:

$$\begin{aligned} J(\alpha, \beta) &= S(\alpha, \beta)S^*(\alpha, \beta) + R(\alpha, \beta)R^*(\alpha, \beta) + \\ &+ S(\alpha, \beta)R(\alpha, \beta) + R(\alpha, \beta)S^*(\alpha, \beta). \end{aligned} \tag{7}$$

It is important to note that the distance of correlation peaks located in the correlation plane is half of the distance of the input and the reference image. This type of optical correlator is less widely used than MF [5], [6] and [7].

3.3. Cambridge Correlator

Optical correlator of Cambridge type (Fig. 5) was designed and constructed at the University of Cambridge. Bearers of the main idea of the technology are Nick New and Tim Wilkinson. It belongs to a group of JTC also referred to as 1/f Phase-Only Joint Transform Correlator. The expression 1/f indicates only a simple Optical Fourier Transform in both stages of the JTC process. This means using the same optics twice in the process of correlation. The term phase only refers to the images being displayed on the SLM in phase, which greatly improves system performance [5], [8] and [9].

1) Optical System

The basis of CC is a unique Fourier Transform Engine©. Compact and powerful data processing system, which is built on the principle of optical diffraction FT. Thanks to the unique distribution of optoelectronic components into a shape resembling the letter "W", the system can use their full potential. This minimizes the distance by which the electrical signals are transmitted, and also optimizes the time needed for processing. In Fig. 5, the main parts of CC are shown [5], [8], [10] and [11].

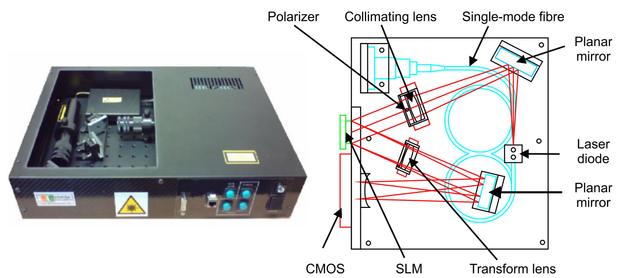


Fig. 5: Main parts of Cambridge optical correlator.

CC consists of several basic optical elements. The first part of elements contains a laser diode and single-mode fibre. Its dimensions are advantages in terms of integration into various devices that are used as CC. The collimating lenses are used to regulate the scattering of the light beam. Polarizer is intended to polarization of the light beam and then it is reflected by planar mirrors. The SLM is located in the system because of storing spatial modulation of the light beam. Currently, there are two kinds of SLM, the Electrically Addressable SLM (EASLM) and Optically Addressable SLM (OASLM). An analyser deals with the analysis of the light beam before it enters the beam transformation lens. The transform lens is obtained by FT of the input scene, which is then processed by a CMOS sensor. Mentioned sensor includes an integrated circuit, consisting of several pixel sensor, while photodetector and active amplifiers are components of each pixel in the sensor. The camera type Leutron PicSight with Gigabit Ethernet interface is used in this device. Frame rate of camera is up to 200 Hz and it has VGA resolution(640×480 pixels) [5], [8], [9], [10] and [11].

2) Fourier Optics Experimenter

CC described above is coupled with simulation software, "Fourier Optics Experimenter" (FOE) for learning and easy understanding of Fourier optics, especially Optical Correlation. FOE can perform Optical Correlation based on CC between two or more images (videos), see Fig. 6.

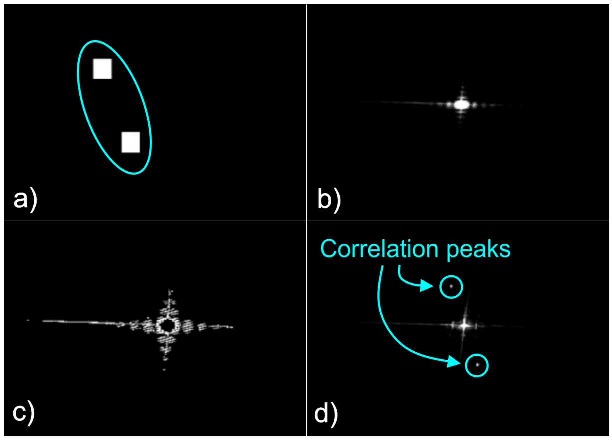


Fig. 6: Process of correlation between same images.

In Fig. 6 we can see process of Optical Correlation between two samples. The input scene (Fig. 6(a)) is created by images mentioned above. We can see JPS in Fig. 6(b) and this JPS binary or threshold processed in Fig. 6(c). The optical output is shown in Fig. 6(d). As it was mentioned above, the optical output contains highly localized intensities and their value might be in within range <0;255> where value "255" refers to total match and value "0" refers to mismatch. The advantage of JTC is ability to do more than one optical correlation at the same time. So, we can compare more images in one correlation process and save process time of recognizing any patterns [8], [9], [10] and [11].

4. Design of Biometric Image Recognition System

Design of systems for biometric image recognition is created because of faster and more efficient processing of the vast amount of information from a database. The term biometric image recognition, in that case expresses the comparison of two images of the eyes or comparing two DNA markers. At first, the image is pre-processed by user-friendly software created in the programming language C#. The obtained image is then compared with the reference image by CC.

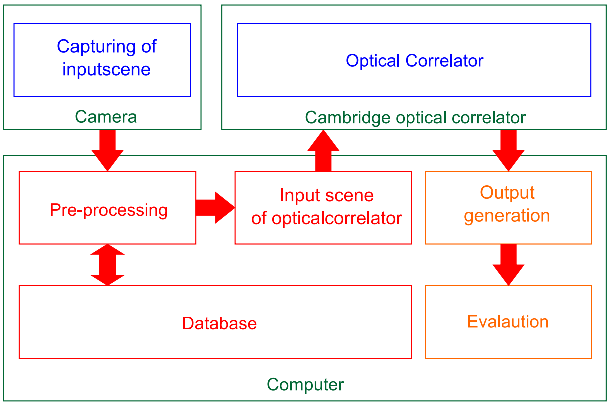


Fig. 7: Block diagram of the eye recognition system.

4.1. Principles of the Eye Recognition System

There are several methods that can be used for the eye recognition. These methods include the identification according to iris and its structure, respectively. Iris is a pigmented internal structure of the eye, where you can notice a number of clearly visible external signs. These features include rings, scratches, spills, stains, and pigment. Each iris is specific thanks to the construction of tissues (muscle fibres, connective tissue, pigment), which are formed. These features should be stabilized in the first year of a person's life.

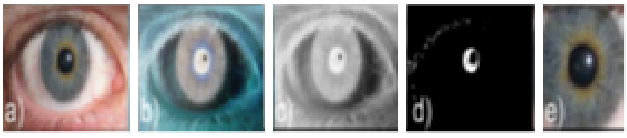
This method is unique in several respects. One of them is the fact that finding two identical irisesby random selection is as less likely asfinding two identical fingerprints. Another fact is that two identical twins can be distinguished from each other by the structure of their irises. Each individual has a unique iris and they are distinguishable from each other. And so from that point of view there is no other outside biometric characteristic of person which would be able to distinguish more people than the iris. While fingerprints can change (growth, burns, cuts, etc.) irises of the eye in humans throughout their life does not change (except for some diseases) [12] and [13].

Block diagram of the eye recognition system is shown in Fig. 7.

In the process of recognition, an image of the eye is scanned at the first stage. This image is then sent to the computer, where it is processed. Image processing consists of multiple processes that are loading, filtration, cropping and creating experimental databases of eyes.

The procedure is shown in Fig. 8. First, the image is:

- loaded Fig. 8(a),
- subsequently inverted Fig. 8(b),
- image is converted by a filter to grayscale Fig. 8(c),
- pupil of the eye is found using a binary image Fig. 8(d),
- the result of the eye image pre-processing is cropped surrounding of the pupil Fig. 8(e).



(a) (b) (c) (d) (e)

Fig. 8: Pre-process of image of eye.

The obtained image is stored in the experimental database and together with the image from the database of reference images they create input image for CC (Fig. 9). All processes associated with control and setting of the input parameters for CC images are performed using software called FOE.

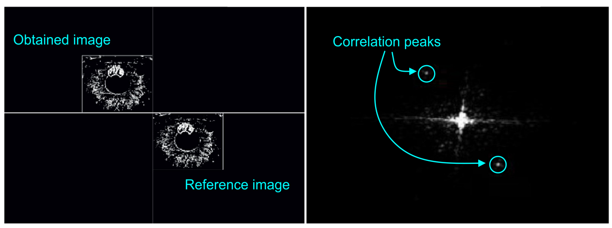


Fig. 9: Input image of CC.

The input image is adjusted by Roberts edge detector. These two images are then transformed and the FT forms their JPS. Then the cross-correlation is executed, which results in correlation peaks with certain values of intensity depending on the degree of similarity of the two images displayed in the correlation plane. Values of intensities obtained by using CC are recorded in a text file that is sent to a computer for evaluation.

4.2. Principles of the DNA Marker Recognition System

DNA profile, also called DNA fingerprinting, is a technique for determining the nucleotide sequence of certain areas of DNA that are unique. Each person has a unique fingerprint DNA. Unlike conventional fingerprint that occurs only on the fingertips and can be altered surgically, DNA fingerprinting is a same for every cell, tissue and organ of a person. It is the ideal way to distinguish the individual from others. DNA fingerprint can be obtained by DNA-extracting from cores of white blood cells or hair follicle cells at the root of the hair falling out or pulling out hair [14].

Applications of DNA fingerprints:

- individuality,
- establishing paternity, maternity,
- detection of hereditary diseases,
- the human race,
- a forensic point of view,
- sociology.

Block diagram of the DNA marker recognition system is similar to previous system (see Fig. 7), but preprocessing is different. The first step is loading an image of DNA markers from the database. Subsequently, a colour filtration is performed as it is shown in Fig. 10.

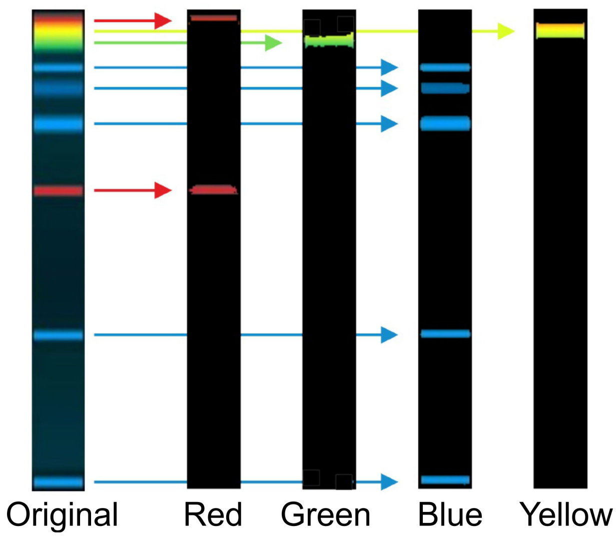


Fig. 10: Colour filtration of DNA marker.

Colour filtration separates colours that are located in the DNA markers (red, blue, green, and yellow) from each other. It is possible to set various different colour combinations depending on the type of DNA markers. From these components of DNA markers, a new database is created. The next step is creation of an input image for the CC from the acquired and reference images. Further steps are in principle the same as it was in the previous subsection in the eye recognition. JPS is created from the input image by FT. The result contains correlation peaks with certain values of brightness depending on the similarity of the two images on the input scene. These values are then saved to a text file which is transferred to a computer for evaluation of these correlation peaks.

5. Experiments and Results

Verification of system for biometric images recognition consists of two parts-verification of eye recognition system and DNA marker recognition system. Both systems contain user-friendly software created by program language C# for input images pre-processing. Pre-processed images are verified by CC. The verification also includes software that enables usage of the correlator-FOE, which provides access to a variety of manual settings of CC.

5.1. Experiments of Eye Recognition System

For verification of system for the eye recognition,an experimental image database of eight different eyes is created. Each image of the eye is pre-processed by created software. The results of this program are eight images of iris of eye (see Fig. 11).

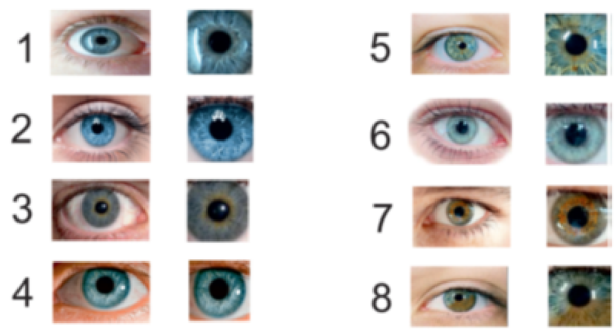


Fig. 11: Experimental image database of eyes.

Pairs of irises are then hundred times compared by FOE and CC. Images of two irises are inserted to input plane of the FOE fordetermining the similarity, whichis shown in Fig. 12.

The first input plane a) contains two identical images;the second input plane b) contains different images. Match of the input images can be detected from the resulting brightness values of the correlation peaks. These values are then entered in a text file.

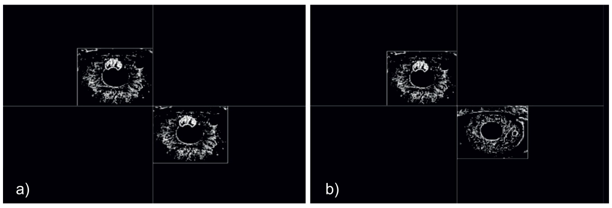


Fig. 12: Input plane of a) same images, b) different images.

A complete overview of the experiments is shown in Tab. 1 and Fig. 13. The average percentages of intensity of compared samples are calculated by the following equation:

$$I_{ID}(\%) = \frac{100 \cdot \bar{I}_{ID}}{255}, \quad (8)$$

where I_{ID} is average value of intensity of two compared samples. This value is calculated by these equations:

$$\bar{I}_{N \cdot sample} = \frac{\sum_{n=1}^{100} I_{N \cdot n \cdot sample}}{100}, \quad (9)$$

$$\bar{I}_{ID} = \frac{\bar{I}_{1 \cdot sample} + \bar{I}_{2 \cdot sample}}{2}, \quad (10)$$

where $I_{N \cdot n \cdot sample}$ isintensity value of sample and $\bar{I}_{N \cdot sample}$ is average intensity of this sample.The threshold value is set to 80%. When the average percentage intensity value of compared samples reaches at least this threshold, the samples are identical.

Tab. 1: Overview of the experiments.

ID	1. Sample / Average Intensity	2. Sample / Average Intensity	Average Intensity (%)
1	Eye1 / 236	Eye1 / 236	93
2	Eye1 / 151	Eye2 / 171	63
3	Eye1 / 172	Eye3 / 160	65
4	Eye1 / 140	Eye4 / 161	59
...	...	...	...
17	Eye3 / 176	Eye4 / 138	62
18	Eye3 / 165	Eye5 / 146	61
...	...	...	...
35	Eye7 / 135	Eye8 / 156	57
36	Eye8 / 235	Eye8 / 235	92

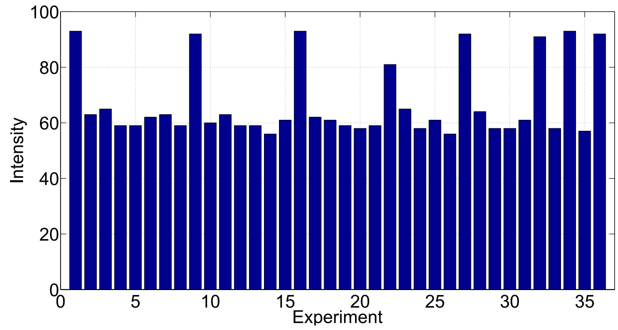


Fig. 13: Overview of the experiments.

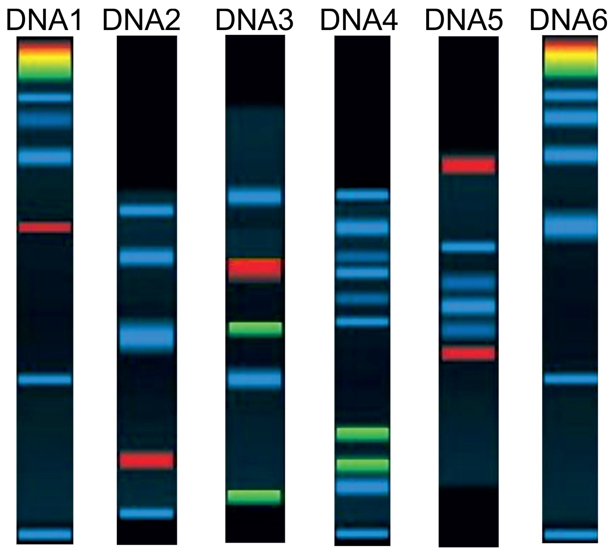


Fig. 14: Overview of the experiments.

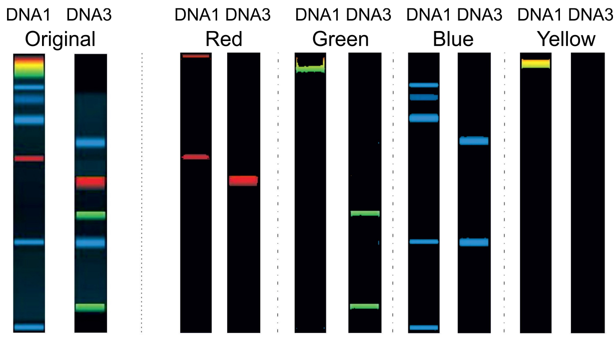


Fig. 15: Comparison of colour components of DNA markers.

5.2. Experiments of DNA Marker Recognition System

Verification of systems for DNA markers recognition consists of experimental verification of the DNA markers (Fig. 14).

The basis of verification is filtration of DNA markers colour components and subsequently comparing the colour components of one marker with second marker (hundred times), see Fig. 15.

A complete overview of the experiments is shown in Tab. 2 and Fig. 16, respectively. For each colour component of DNA marker, the average value of intensity is calculated by Eq. (10). A positive evaluation is based on the fact that intensity value of each colour components is above than set value of 220. In this case, the markers are considered as identical. If at least one colour components intensity value is below a set value, then compared DNA markers are considered to be different.

Tab. 2: Overview of the experiments.

ID	1. Sample	2. Sample	Intensity (R)	Intensity (G)	Intensity (B)	Intensity (Y)
1	Marker1	Marker1	235	234	235	233
2	Marker1	Marker2	110	0	134	0
3	Marker1	Marker3	118	67	71	0
4	Marker1	Marker4	0	43	74	0
...	...	...	...	...	...	...
13	Marker3	Marker4	0	52	39	255
14	Marker3	Marker5	98	0	57	255
...	...	...	...	...	...	...
20	Marker5	Marker6	46	0	73	0
21	Marker6	Marker6	231	234	233	232

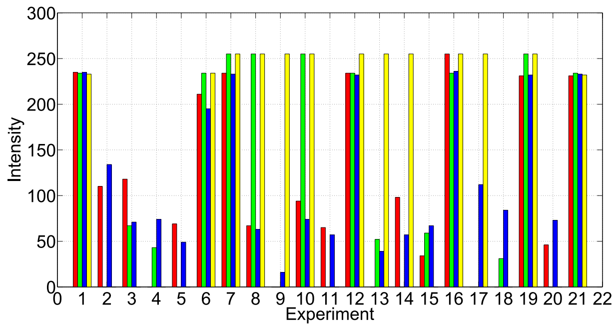


Fig. 16: Overview of the experiments.

6. Conclusion

In this paper, system for recognition of biometric images has been described. This system contains of two systems - eye recognition system and DNA marker recognition system. Both systems use user-friendly software created in programming language C# to extract and pre-process input images. These images are compared with reference stored in experimental database by CC. Software FOE is used for comparing, which is inseparable component of CC. The result of comparison was intensity of correlation peaks. The average values of intensities and percentage match of compared images were obtained.

Eight images of iris of the eye were created and then compared. 3600 experiments have been done and the functionality of eye recognition system has been verified. Intensity value of the same images was always greater than 200 (80 %) and for different images, this value was not greater than 166 (65 %).

The system for DNA marker recognition is based on comparison of DNA marker colour components. 2100 experiments have been done and the functionality of DNA marker recognition system has been verified. The same images had intensity value of each colour component higher than 220. In the case, when both DNA markers did not contain a specific colour component, these components were considered as identical.

The system for biometric images recognition - eye and DNA marker, was verified experimentally. Optical image processing done by CC has some potential in biometrics. Also, CC could be implemented in many other areas where the speed and accuracy is important. The system can be extended to the fingerprint and palm recognition system in the future.

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