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New Experiments with Optical Liveness Testing Methods

Martin Drahansky and Dana Hejtmankova

Department of Intelligent Systems
Faculty of Information Technology
Brno University of Technology
Bozetechova 2, Brno, 612 66, Czech Republic
drahan@fit.vutbr.cz; hejtmanka@fit.vutbr.cz

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Abstract. This article describes experimental results, which have been achieved from our three realized solutions of liveness detection. These liveness detection solutions were patented (international patent WO/2007/036370, Czech utility model UPV19364) and theoretically introduced in the previous work. First solution is based on detection of changes of distance between neighbor papillary lines caused by pulse, second is based on detection of volumetric changes by the use of laser distance sensor and third on causation of optical changes. This article is oriented on the description of obtained results from realized experiments. There has also been developed a special optical bench for the measurement of our methods.
Keywords: Liveness detection, fingerprint, biometric system, pulse, elasticity, causation of optical changes.

1. **Introduction.** Securing automated and unsupervised fingerprint recognition systems used for the access control is one of the most critical and most challenging tasks in real world scenarios. Basic threats for a fingerprint recognition system are repudiation, coercion, contamination and circumvention [8, 9]. Variety of methods can be used to get an unauthorized access to a system based on the automated fingerprint recognition. If we neglect attacks on the algorithm, data transport and hardware (all these attacks demand good IT knowledge), one of the simplest possibilities is to produce an artificial fingerprint using soft silicon, gummy and plastic material or similar substances [13, 1, 7].

The fingerprint of a person enrolled in a database is easy to acquire, even without the user's cooperation. Latent fingerprints on daily-use products or on sensors of the access control system itself may be used as templates. It is easy to take a photograph of such latent fingerprint, enhance it by the use of program for image editing and have to make a common office rubber stamp of fingerprint [5, 4]. This stamp can be easily used for deception of common types of fingerprint sensors as optical, capacitive and thermal (see Fig. 1).

To discourage potential attackers from presenting a fake finger (i.e. an imitation of the fingertip and the papillary lines) or, even worse, to hurt a person to gain access, the system must be augmented by a liveness detection component [8, 9]. To prevent false acceptance we have to recognize whether the finger on the plate of the fingerprint sensor (also referred to as fingerprint scanner) is alive or not. Recently, several methods for liveness detection has been published. They proposed liveness testing based on body odor [2], perspiration

[12], relative dielectric constant [14], etc. Unfortunately, results of these methods are not good enough for practical use.

FIGURE 1. The stamp captured by thermal fingerprint sensor Bergdata FCAT 100 (left fingerprint), by optical fingerprint sensor Suprema SFM3020-OP (middle fingerprint) and by capacitive fingerprint sensor Suprema SFM3050-TC1 (right fingerprint). Picture of the stamp (right picture). [5].

2. **Description of Methods.** In [8, 10], two approaches for measuring of fine movements of papillary lines, based on optical principles, are suggested (Fig. 2). The first solution is based on a close-up view of the fingertip acquired with a CCD camera; the second one is distance measurement with a laser sensor. Third method is based on causation of optical changes and it was suggested in [3, 5]. It should be noted that adding these liveness detection solution to a ngerprint recognition system, as proposed in Fig. 3, may significantly influence the hardware requirements imposed on the complete system.

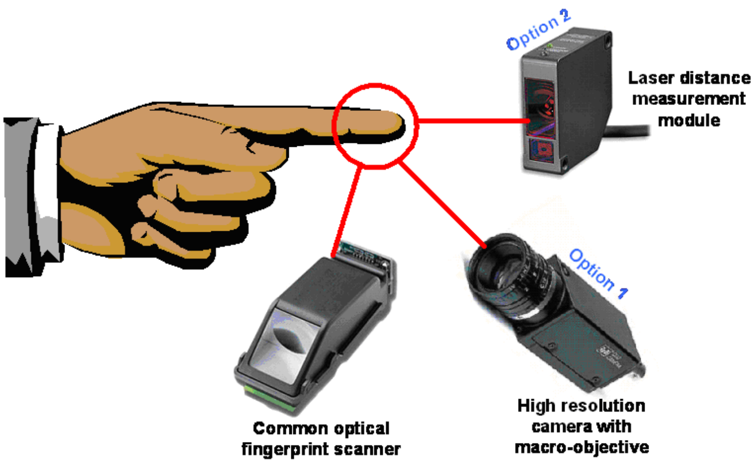

FIGURE 2. Integrated liveness detection - scanner + optical and laser solution [4].

2.1. **Camera Solution.** The camera solution scheme is outlined in Fig. 3. The main idea is that a small aperture (approximately 6 mm) is created in the middle of a glass plate with an alternately functioning mirror below the plate. First, during the fingerprint acquirement phase, the whole fingerprint is stored and the system operates as a classical fingerprint acquisition scanner (mirror permeable) by projecting the fingerprint on the CCD/CMOS camera. Next, in the liveness detection phase, the mirror is made impermeable for light and a part of the fingertip placed on the aperture is mirrored to the right and projected on the CCD/CMOS camera by a macro lens. The latter part of the system is used to acquire a video sequence for the liveness detection analysis.

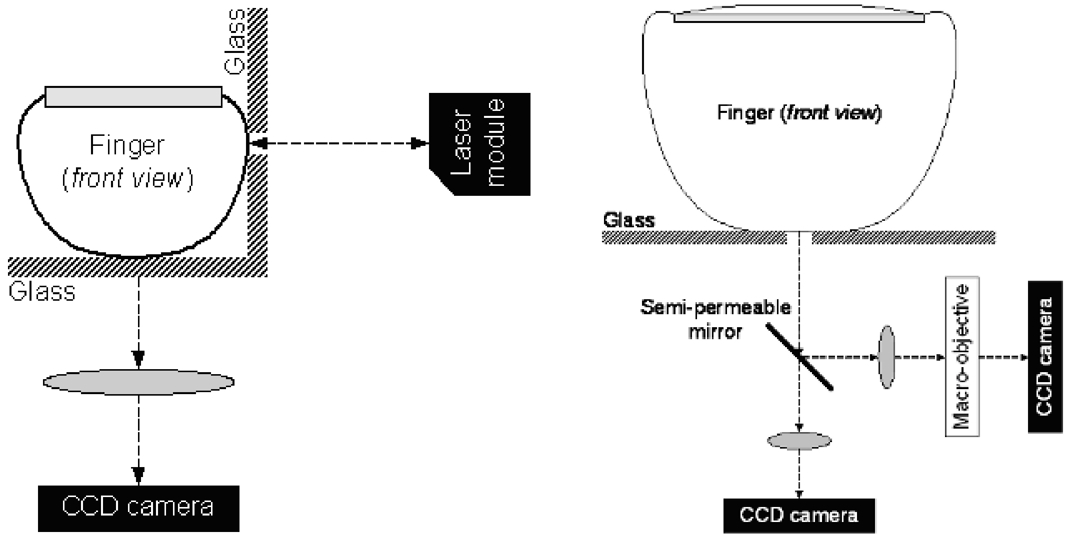

FIGURE 3. Left schema: Possible integration of a camera-based measurement system for liveness detection with optical fingerprint sensor (CCD/CMOS camera). Right schema: Possible integration of laser distance measurement for liveness detection with optical fingerprint sensor (CCD/CMOS camera; aperture approx. 6 mm) [8].

2.2. **Laser Solution.** The second optical method for the liveness testing is based on laser distance measurements [8, 10]. Fig. 3 outlines the laser distance measurement module, which could be integrated with a standard optical fingerprint sensor. The optical lens system and CCD camera for acquisition of the fingerprint are the same as in Fig. 3. However, unlike the solution shown in Fig. 3, the laser distance measurement module is placed to the right side of the glass plate, which is L-shaped here. The user places his finger in such a way that it is in contact with the horizontal and the vertical side of the glass plate.

The underlying physical measurement principle is the same as in the video camera solution. We assume volume changes (expansion and contraction) due to the heart activity, which causes fine movements of the skin. The laser sensor is able, based on the triangulation principle, to measure very small changes in distance down to several μm. The comparison of the computed curve and a normalized standard curve (the template) will reveal whether the measurement corresponds to a standard live fingerprint or indicates a fake finger or another attempt of fraud. For example, the comparison between both curves can be realized by the normalization followed by the cross correlation. The optical bench (designed by us) used for experiments is shown in Fig. 4.

2.3. **Causation of Optical Changes.** Third method for liveness detection is based on causation of optical changes [5, 3]. The optical changes (the change of width and color of papillary lines) are caused by pressing the finger against a sensor surface (glass plate). These optical changes can be seen in Fig. 8. The finger in the left is captured before and the finger in the right after the pressure. You can see the change of color of papillary lines from reddish to yellowish. This change could be observed mostly in a green part of RGB color model (approx. several tens of points). It also can be observed an increase of width of papillary lines (approx. several tens of percent) in the pressed area of finger. However, the concrete values of color change and change of width of papillary lines depend on the force of pressure.

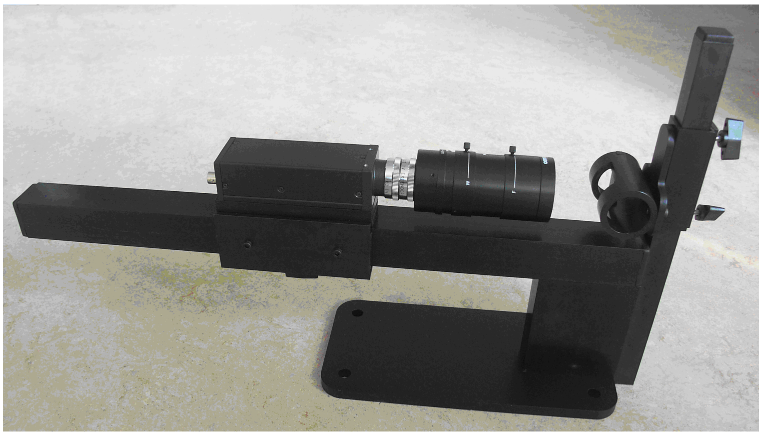

FIGURE 4. Photo of optical bench for measurement by two above mentioned camera-based methods.

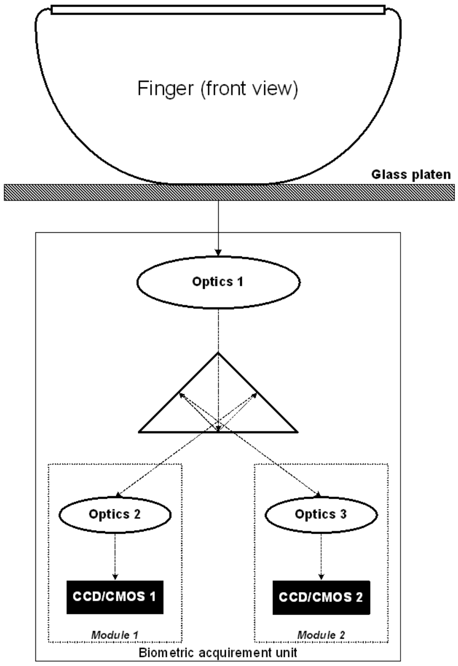

FIGURE 5. Scheme of the optical sensor with liveness detection based on the causation of optical changes as a two-camera system [5, 3].

Both these changes have to be detected simultaneously and continuously in a video stream. Otherwise (in case of system which take only two pictures), an attacker could create two artificial fingerprints (each with different color of finger and width of papillary lines) and exchange them to deceive the sensor.

Whole system is possible to construct as sigle-camera or two-camera system. Two-camera system has lower requirements for both cameras (in comparison with one-camera system), so it can be cheaper, but more space consuming solution. First camera could have grayscale output and lower image frequency, but has to have high image resolution for purposes of measuring of change of papillary lines width. Second camera has to have high image frequency and color output, but it can have lower image resolution. This camera is used for color change detection. The whole system shall also to have a prism and the appropriate optics. The scheme of whole system could be found in Fig. 5.

3. **Realization of Experiments.**

3.1. **Camera Solution.** In [11], there are described some experiments using the resulting images (video sequences) from our installations. Within the scope of this work, fifteen videos have been acquired (covering 3 users and 5 fingers) with the duration of 15 seconds each and zooming 10. The following equipment has been used:

- Industrial camera Sony XCD-SX910CR (Fire-Wire),
- Macro-objective Computar MLH-10x,
- Illumination unit - LED Osram Golden Dragon LCW W5SM (white),
- Sanitas SBM 04 - medical blood pressure and pulse measurement device.

From these video sequences, 220 images containing each frame from the whole video file have been extracted. These image files were subjected to an analysis using two applications or procedures (manual and automatic) implemented for this purpose. The application for the manual measurement of distance changes makes possible to set manually the positions of relevant points (areas with the highest luminosity - the analyst had to find such points and to put the mouse cursor on them) in the image with papillary lines extracted from the video sequences. The automatic application finds the most sensitive points (pixels with the highest luminosity) in the image and computes automatically the distances in the whole image sequence.

The optical bench (designed by us) used for experiments is shown in Fig. 4.

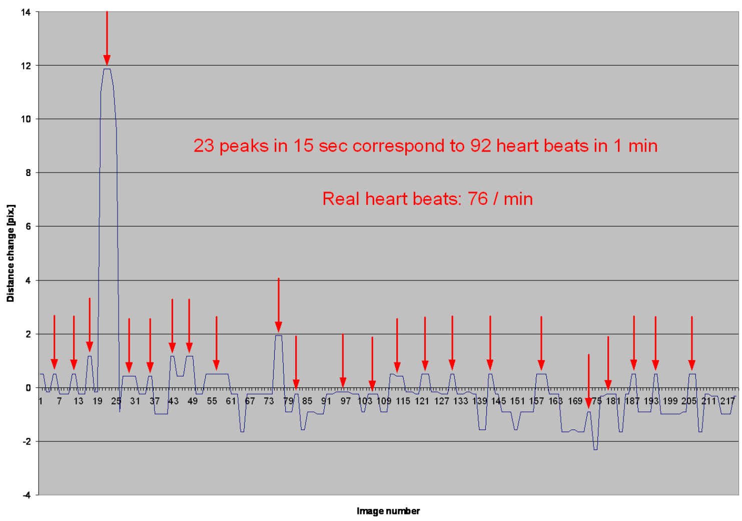

FIGURE 6. Analysis of the optical sequence.

Always 5 distances were used, whereas the end points (circles) have been selected only by manual setting (the user places the end points (circles) using a mouse cursor (a cross) and by clicking with the left mouse button). In the automatic modus, these circles are shown only in the first image, while in the following images only the abscissas are shown - the reason is to be able to control the right positioning of the end points by the user.

It is evident that the manual setting of end points for the measurement of distance changes is inaccurate - due to the inaccurateness in the correct positioning of the mouse cursor to the always same position. The distance changes vary significantly and do not show any periodical behavioral. In addition, in the real world, it is not possible to perform the liveness detection in a manual way. On the other hand, the algorithm in the automatic application puts the end points of an abscissa for distance measurement always to the same position (pixels with the highest luminosity are detected automatically) - however there can be some instability in finding such end points due to the variation of luminosity in the surroundings, what could lead to finding of the neighboring point (a tolerance box of 5 points has been used).

Although some fine changes appeared in illumination caused by hand shaking, some periodical curve runs can be found - see Fig. 6.

The medical blood pressure and pulse measurement device Sanitas SBM 04 (produced by Hans Dinslage GmbH) was used for the comparison of measured heart beats with the real ones during all video acquirements.

You can see in Fig. 6 that 23 local maximal values (peaks) were found which might correspond to heart beat impulses. These 23 peaks in a 15-second interval indicate that the pulse rate is 92 heart beats per minute, what does not correspond to the real (conventionally measured) value of 76 heart beats per minute. The difference could be caused by the previously mentioned change of illumination, which led to the movement of the previously found pixel to the neighboring pixel in some cases and therefore to the distance change resulting in incorrect peaks. No filtering of the curvature has been used. We can only state that after the filtering and computation of a probable periodical behavioral, it would be possible to make some relevant statements about the liveness of the user. The resolution could collide with the wavelength of the light - it is possible to do this optical measurement of distance changes between two papillary lines, because the changes are in some micrometers.

3.2. **Laser Solution.** For the second experiment with the liveness detection based on a laser module solution we have used a Panasonic LM10 laser connected to an oscilloscope. The LM10 device is well suited for measurements with the accuracy 1μm and works with the wavelength 685 nm. The measurement principle is based on triangulation. The following equipment has been used:

- Laser module Panasonic LM10 ANR1250,
- Control unit Panasonic LM10 ANR5132 for the laser module,
- Oscilloscope Tektronix DPO7254,
- Contec CMS-60C - medical pulse oximeter.

One example of the acquired curve (screenshot of the oscilloscope) is shown in Fig. 7. There is very well recognizable periodical behavioral of the curve - the period corresponds to the heart activity. An analysis of the acquired signals has been performed - see Fig. 7, the curve has the following attributes:

- Axis x: time, 500 ms / division.
- Axis y: voltage, 20 mV / division.
- 5 periodical runs (heart beats) in 4,42 seconds means 67,87 heart beats per 1 minute.
- Real heart beat rate (measured by Contec CMS-60C): 68 per min, so he concordance of computed and conventionally measured values is very good.

We tested this approach on the group of 7 volunteers (men and women from 22 to 52 years old). Every volunteer tested one finger in two session and the measuring by the use of pulse oximeter run simultaneously with the measuring by the use of laser distance sensor. The concordance between the results from oximeter and laser distance sensor was very good - the average difference between these two values was 2,55.

When summarizing the results of method for liveness detection based on the laser measurement principle, we can say that this method is very reliable, quick (several seconds are needed for the detection of a periodical run in the curve) and does not need very much

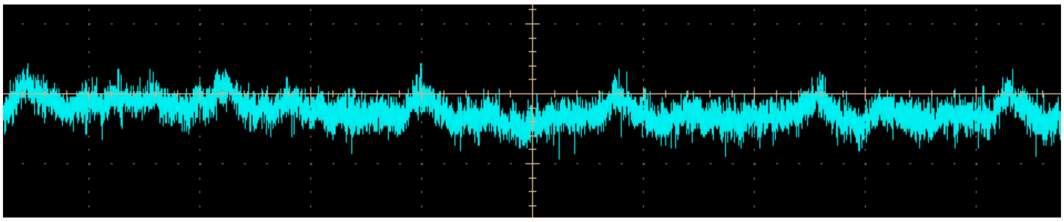

FIGURE 7. Analysis of the pulsation curve (screenshot from oscilloscope).

performance from the processor, i.e. it is quite simple for computation. However, the disadvantage of this method lies in an expensive laser module and space requirements - it is not possible to integrate such solution in common, very small ngerprint scanners, with perhaps one exception of optical sensors, as their physical principle of functioning leads to bigger device constructions.

3.3. **Causation of Optical Changes.** The third liveness detection solution was first tested by the use of common office scanner, because the optical bench was not fully prepared yet [5]. This preliminary test with a small group of volunteers was focused on verification whether this approach could work for volunteers of different gender and race (Caucasian, African, Asian). We captured right thumb and index finger in three sessions and every finger in pressed and not-pressed position (see Fig. 8). The captured fingerprints were evaluated by the semiautomatic program. The difference between green values was approximately 50 and the extension of papillary lines was about a few tens of percent. However, both values were highly dependent on the strength of pressing.

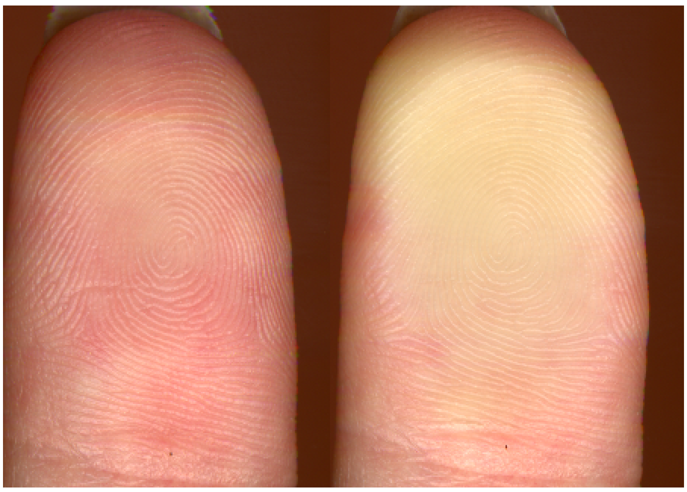

FIGURE 8. The finger before (left image) and after (right image) applying of pressure against glass plate.

During last few months we performed second and wider tests. For the purposes of these tests following equipment has been used:

- Industrial camera Sony XCD-SX910CR (Fire-Wire),
- Macro-objective Computar MLH-10x,
- LED diode (white, wide angle),
- Optical bench 4 with a special end-part.

These tests were performed by the help of 155 volunteers (men and women, Caucasian). For the purposes of these tests, the special end-part for the optical bench was created. This end-part was specially designed for left-handed and right-handed people and also it is intentionally robust, so the volunteers do not worry to press their finger hardly against the glass plate.

The result of these tests was very good. Result of each volunteer was within the interval for live human being. Among these tests our volunteers tried to spoof this solution by the use of artificial ngers made from Latex or Durocast, but they were not successful.

4. **Conclusions.** The camera solution offers relative cheap possibility of liveness detection, however the accuracy is very low and there are many problems in image processing and correct distance measurement between papillary lines. This solution might be suitable, but is not recommended by us for commercial use in systems with high demands on security.

The laser solution offers more reliable liveness detection tool. On the other side, this method is more expansive and a special laser distance measurement module has to be purchased, what could be seen as a disadvantage. Nevertheless, if the finger is placed on the right position and fixed, the reliability of heart activity recognition is very high; therefore we recommend this method for biometric systems with high security demands, where the liveness detection plays a crucial role.

The method based on causation of optical changes is also very promising. In case of two-camera approach, it can be cheaper than laser solution, but it is also more spatially demanding. The reliability of this liveness detection is also very high and we recommend this method for not-touchless fingerprint systems with high security demands.

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