Multi-Spectral Imaging of Fingerprints for Secure Biometric Systems

Masashi Kurita, Katsuki Tai and Ichiro Fujieda, Ritsumeikan University, Japan

Abstract

Fingerprints identification systems are accepted gradually in the world. However, they can be fooled by artificial fingers (replicas) and this fact is reported in the literatures and the Internet. Therefore, life recognition is desired for unattended fingerprint identification. We look at the color changes in a series of fingerprint images acquired during the course of an input action. As we press a finger upon an input device, a fingerprint area gradually increases and its color changes. This is due to the blood movements induced by a finger deformation. A fingerprint sensor based on scattered-light detection can detect this information on the blood movement inside a finger more clearly than a conventional sensor using a prism. In order to extract more information from a finger-tip, we consider an input device equipped with light sources emitting in different narrow wavelength bands, namely a multi-spectral fingerprint sensor. In experiment, we used two LEDs emitting in the visible light and turned them at the same time. From a series of fingerprint images captured by a CMOS camera, we extracted the characteristic of color change of live finger. However, there are not characteristic such as them by replica. This difference can be utilized to reject replicas for fingerprint identification.

Introduction

Biometrics based on fingerprints are already commercialized and used to replace passwords in personal computers, mobile telephones, etc. These technologies might gradually enable general public to accept new services such as electronic commerce, electronic government, etc. Deterrence of crimes in cyberspace and terrorism prevention at critical facilities like airports and nuclear reactors, etc. are more direct benefits. However, techniques to fake such fingerprint identification systems are reported in the literatures[1,2] as well as on the Internet.[3] Especially, the threat by artificial fingers needs to be addressed.

For rejecting replicas, we have proposed a method to check characteristic changes on color and area in a series of fingerprint images acquired during an input action.[4] Its principle is shown in Figure 1. When we press a finger on a sensor, it is deformed and the fingerprint area gradually increases. As the pressure applied to the finger is decreased, the area becomes smaller. When we press a finger on a sensor, the finger becomes whiter. As the pressure is decreased, the finger becomes reddish. This is due to the blood movements in the finger induced by the finger deformation and this phenomenon can be applied for rejecting replicas.

A fingerprint sensor based on scattered-light detection[5] can detect this information on the blood movement inside a finger more clearly than a conventional sensor using a prism.[4] Its configuration is illustrated in Figure 2. It consists of a light source, a light-guide, a lens and an image sensor. The principle is described as follows. The light source is mounted on an edge of the light-guide and light propagates inside the light-guide by repeating total internal reflection at the interface of the light-guide and air. A part of the propagating light is scattered at the ridges of a finger pressed on the plate (the light-guide). The light also enters the finger and is scattered inside the finger. Since this component carries the information on the blood movement, it is important for our life recognition method. Since the propagating light cannot escape the light-guide at the valley regions of the finger, the contrast of the fingerprint is optically enhanced.

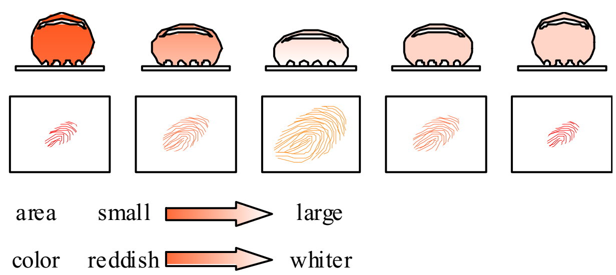

Figure 1. Life recognition principle based on color and area variations

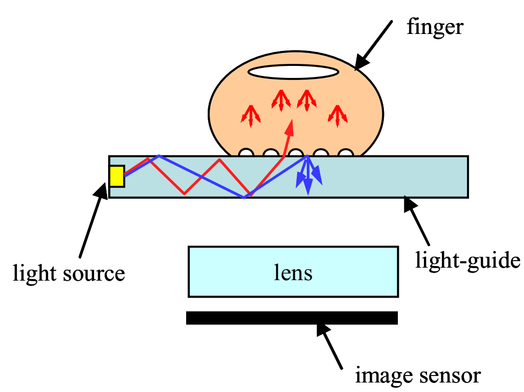

Figure 2. A sensor based on scattered-light detection.

In our previous experiments, the color changes were detected by means of a white light source and color filters built on the picture elements of an image sensor. In order to extract more information from a finger-tip, we consider an input device equipped with light sources emitting different narrow wavelength bands, namely a multi-spectral fingerprint sensor.

The aim of this study is to make life recognition more reliable by extracting more information from a live finger. We will show how this is done with new versions of fingerprint-input systems. In these experiments, four volunteers, as listed in Table 1, and the three kinds of replicas listed in Table 2 and shown in Figure 3 are used.

Table 1: Participants for the Experiment

volunteer	age	sex
A	22	male
B	22	male
C	26	male
D	23	male

Table 2: Three Kinds of Replicas

#	Materials and structures
1	Silicone(yellow)
2	Silicone(skin-colored)
3	Urethane resin + chopstick

Figure 3. Photographs of the replicas

Spectral Reflectance of a Finger

Before constructing such an input device, we have measured spectral reflectance of a live finger and a replica. The purpose for this is to see how live fingers and replicas behave differently when they are deformed.

The experimental setup is similar to the sensor based on scattered-light detection[5] and it is composed of a light source, an acrylic plate, a pressure sensor, and a spectrometer. When a live finger or a replica touches the plate, the pressure sensor mounted at the edge of the plate monitors the pressure applied to the plate by the finger. An optical fiber is used to guide the light scattered by the finger to a spectrometer. The first spectrum is recorded when a live finger is pressed softly against the plate. More spectra are recorded as the pressure is increased by a pre-determined value. This is repeated with a replica. All the spectra are normalized so that the total numbers of the detected photons are equal.

We asked volunteers A, B and C in Table 1 to participate in this experiment and used all the replicas listed in Table 2. Representative data for the live fingers and the replicas are shown in Figure 4 and Figure 5, respectively.

In these results, the legend "no pressure" means that the fingers are pressed softly against the plate. Other legends refer to the amount of the pressure monitored by the pressure sensor, which is varied form 1.3N to 6.5N with a step of 1.3N.

The following observations stand for all the live fingers tested here. First, there is a significant difference in the wavelength region from 520 nm to 600 nm and the intensity of the scattered-light increases with the pressure. Second, there is another notable difference in the wavelength region above 600 nm, that is, the scattered-light intensity decreases with the pressure. On the other hand, the replica shows similar reflectance spectra irrespective of the amount of the pressure.

In summary, there is a significant change in the reflectance spectra when the live fingers are deformed. Reflectance spectra of the replica do not change even when it is deformed.

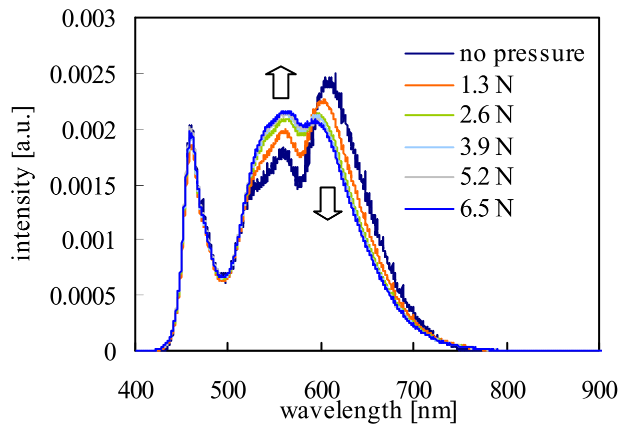

Figure 4. Spectral reflectance of the live finger (volunteer A)

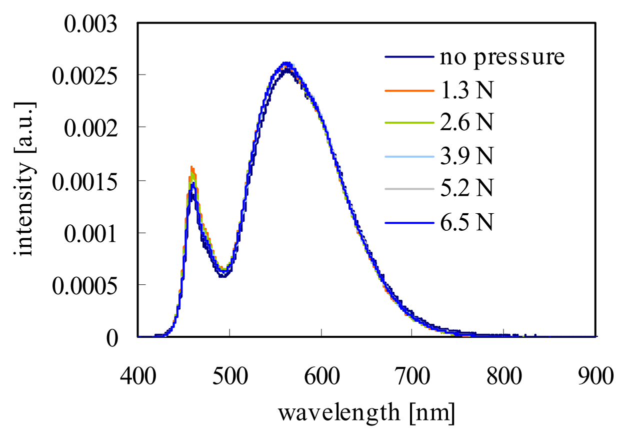

Figure 5. Spectral reflectance of the replica 1

Multi-Spectral Imaging

Sequentially Turned Light

Most LEDs have narrow bands of emission wavelength. If we use plural LEDs of different emission wavelength bands and an image sensor with color filters, we can obtain spectral reflectance of a finger approximately. Here, we describe such a multi-spectral imaging for a secure fingerprint identification system.

First, we discuss the choice of the LEDs to be used. Keep in mind that there is a big characteristic change in a reflectance spectrum in the wavelength regions between 520 nm and 600 nm and above 600 nm for a live finger. We need multiple LEDs to cover these wavelength ranges. For this experiment, we chose five LEDs which were readily-available to us. The emission spectra of these LEDs are shown in Figure 6. The peak wavelengths are 470 nm, 540 nm, 625 nm, 668 nm and 690 nm. These spectra are more or less separated from each other with the exception of that of the 690nm-LED.

Second, we describe the input sequence of this multi-spectral imaging system. We use a standard inter-laced color CCD camera as an image input device. Three color filters are built on the photo-sensitive elements and three sub-images are obtained. The first signal in the timing chart in Figure 7 is the driving pulse for the CCD camera. The frame rate is 30 fps. The LED emitting in the 1st band of the spectrum is turned on during the first frame. The video output of the CCD camera during the second frame carries the information for this band of light. The second LED is turned on during the third frame to avoid mixing signals generated by the two bands of light. The third frame of the camera output is discarded. This sequence is repeated for the remaining three LEDs.

Third, we describe the method for extracting meaningful information. The video output of the CCD camera is converted into a number of still images. Only the images taken when the LEDs are turned on are retained and the rest is discarded as described above. Spectral and area information is extracted from the retained images. Here, we define “area signal” as the number of pixels whose values exceed a certain threshold value. And we define “color signal” as the average pixel value for a small central portion of the fingerprint image corresponding to each of the five LEDs.

For example, the color signal for the 1st LED (the blue band of the spectrum) is shown in Figure 8. This example was obtained with a live finger. There are two characteristic points we can identify. One is the initial point of the trajectory (marked as “no pressure”). The other is the point when the area signal becomes the largest (marked as “under pressure”). We will record the coordinates of these two points in the following experiments.

Volunteers A, C and D in Table 1 participated in this experiment and we used the same replicas described in Table 2. The data acquisition and analysis were repeated three times for each live finger and replica. The representative results obtained by the three live fingers and the three replicas are shown in Figure 9 and Figure 10, respectively. In these results, the dotted lines marked as “no pressure” are the data obtained when the fingers are pressed softly against the plate. The solid lines marked as “under pressure” are the data obtained when the pressure is increased by a fixed amount.

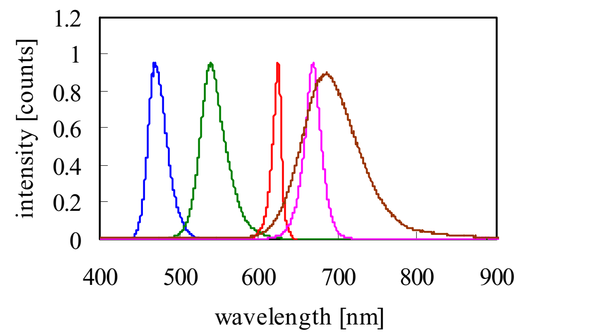

Figure 6. The emission spectra of the five LEDs used in this experiment

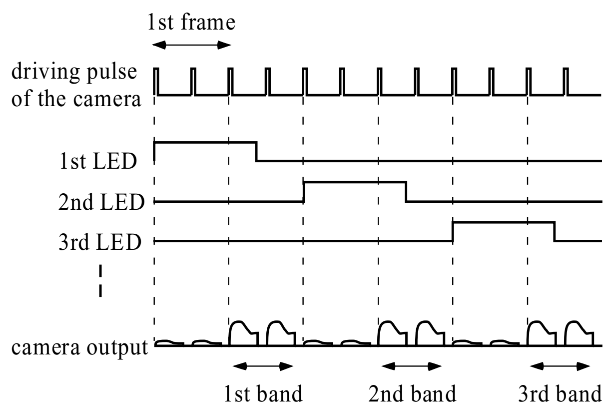

Figure 7. Driving sequence for the multi-spectral imaging

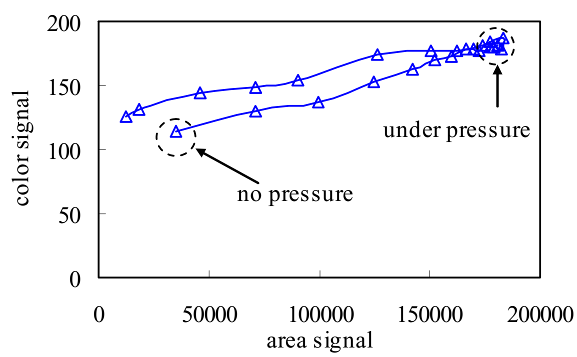

Figure 8. Example behavior of the color signal obtained with a live finger (volunteer A)

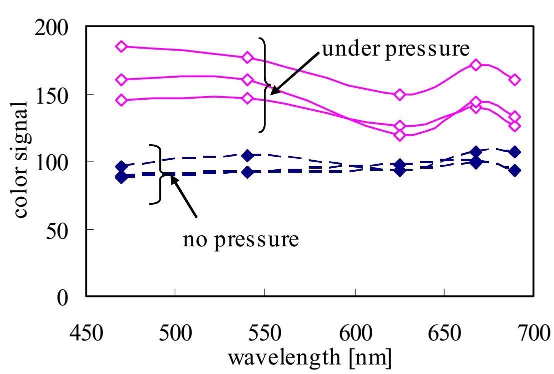

Figure 9. The result of multi-spectral imaging of the live fingers (volunteer A, C and D)

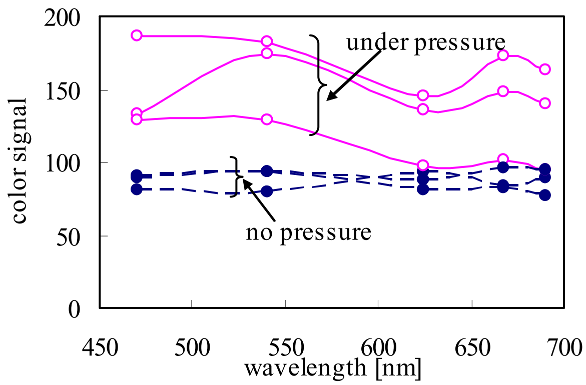

Figure 10. The result of multi-spectral imaging of the replicas (replica 1, 2 and 3)

We can observe the variations among the individuals in Figure 9. But these "color signals" show a common dependency on the wavelength when the pressure applied to a finger is changed. Namely, the color signal decreases when the wavelength increases from 470 nm to 625 nm. It increases when the wavelength is 668 nm. In Figure 10, the replica 1 showed a tendency different from the live fingers. But the replica 2 and 3 showed a tendency similar to the live fingers.

Dual LED Light Source

It might be adequate to use LEDs emitting in the wavelength ranges where the most characteristic changes occur for a live finger.

In the previous section, we found the fact that there is a significant difference in the wavelength regions between 520 nm and 600 nm and above 600 nm. For this experiment, we chose only two LEDs covering these wavelength ranges. The emission spectra for these LEDs are shown in Figure 11. The peak wavelengths are 535 nm and 625 nm. We turn on these LEDs at the same time.

We use a standard CMOS camera to capture a series of fingerprint images in this experiment. As in the previous section, we define the area signal and the color signal (R and G) in the same manner. These color signals are normalized by,

$$R' = R / (R+G), \quad G' = G / (R+G). \tag{1}$$

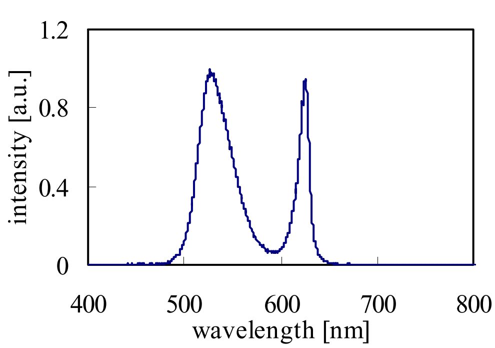

Figure 11. The emission spectra of the two LEDs used in this experiment

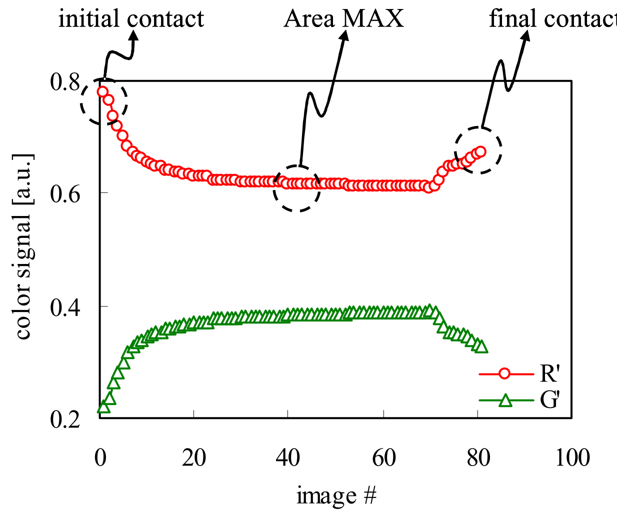

Figure 12. Color signals extracted from the images obtained with a live finger (volunteer A)

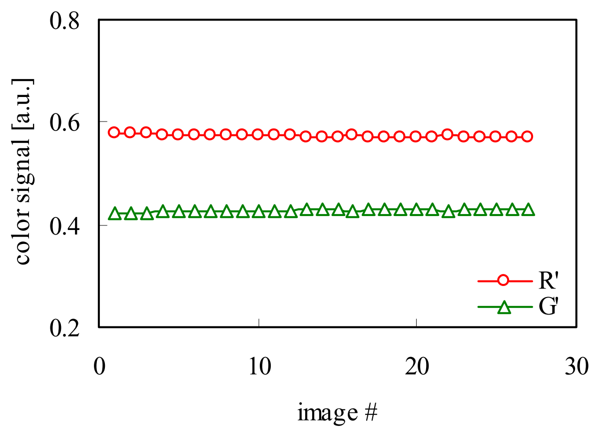

Figure 13. Color signals extracted from the images obtained with a replica (replica 1)

Results for a live finger and a replica are shown in Figure 12 and Figure 13, respectively. The horizontal axis of Figure 12 is the image number for the sequential fingerprint images. Here, there is a significant difference between the live finger and the replica. For quantifying this difference, we label three points as "initial contact" "Area MAX" and "final contact" in the Fig. 12.

A simplified version of Fig. 12 is shown in Figure 14, where we focus on the change of R'. We define $\triangle R'_i$ as the difference of the normalized color signal R' between "initial contact" and "Area MAX" as defined in Fig. 12. We define $\triangle R'_f$ as the difference between "Area MAX" and "final contact". These indices, $\triangle R'_i$ and $\triangle R'_f$, are compared for the live fingers and the replicas. We asked three volunteers (A, B and C) in

Table 1 to participate in this experiment and used the same replicas described in Table 2. The data acquisition and analysis were repeated three times for each index finger and replica.

The results are summarized in Figure 15 and Figure 16. In these results, the horizontal axis is the ages of the participants and the replicas are assumed to be one year old.

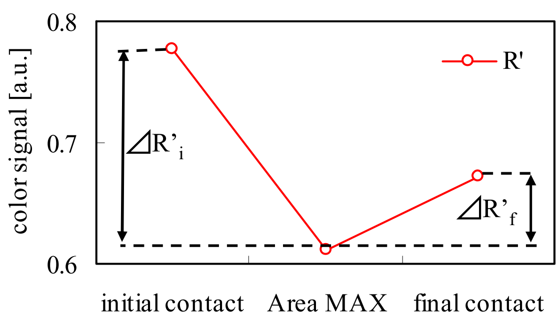

Figure 14. A simplified version of Fig.12 and the definitions of the indices

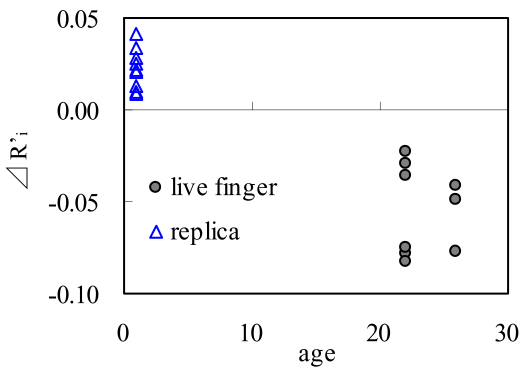

Figure 15. The result for ⊿R'_i

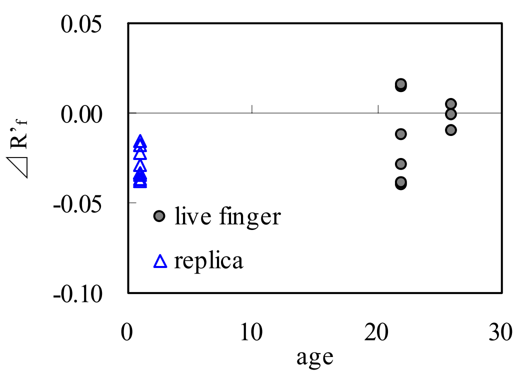

Figure 16. The result for ⊿R'_f

In Fig. 15, the index ⊿R'_i shows a clear difference between the live fingers and the replicas. On the other hand, the index ⊿R'_f does not work well. In summary, we could show that it is possible to determine a finger is alive or not. For example, we set the threshold for life recognition for the index ⊿R'_i to be -0.01. If ⊿R'_i is below -0.01, we can judge the finger is alive.

Conclusion

Life recognition is desired for unattended fingerprint identification. For rejecting well-designed replicas, we need to extract life-related information from a finger-tip as much as possible. Reflectance spectrum of a live finger and its pressure dependency carry information about the blood movement induced by finger-deformation. We have proposed multi-band spectral imaging of a finger for rejecting replicas. In experiment, we used five LEDs emitting in the visible and near-infrared light and turned them sequentially. From a series of fingerprint images captured by a standard color CCD camera, we extracted the five-band spectral information from live fingers and replicas. As a simplified version of this multi-band system, we have proposed a dual-LED light source, using LEDs emitting around 535 nm and 625 nm. We have found characteristic changes of live fingers and shown that they could be utilized to reject replicas for fingerprint identification.

Reference

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Author Biography

Masashi Kurita received his B.S. from the department of Photonics, Ritsumeikan University in 2005. He is currently a graduate student in the master's program at Ritsumeikan University and is working on fingerprint input systems and related subjects, including signal processing for life recognition and health-monitoring applications.