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The Fingerprint Capture Method Based on Waterproof Optical Design for Fingerprint Analysis and Enhanced Fingerprint Recognition Technology

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Abstract: The most common sensor technology which is currently used in fingerprint recognition is the optical technology. The optical-type sensor is available for the unspecified number (1:N) and is capable of obtaining the durability and high fingerprint image quality. In this study, we are willing to improve the problem of optical sensor which is hard to extract the fingerprint minutiae via. binarization and to extract the difference between the ridge and valley of fingerprint when there is a lot of water or sweat on the fingerprint surface. Therefore, the structure of the prism was designed to distinguish between sweat and water and SF4 material with a small influence of refractive index was applied. In addition, spherical lenses G1 and G2 were designed and implemented to correct trapezoidal distortion and reduce cost. To demonstrate the superiority of the study results, we compared the image quality map of NIST and the minutiae distribution using fingerprint recognition technology. The result shows the proposed sensor has the high NFIQ quality score in all normal and wet fingerprint.

Key words: Biometric, optical fingerprint sensor, prism design, ridge and valley, NIST quality map, NFIQ quality

INTRODUCTION

The fingerprint recognition technology is one of common technologies in all biometric recognition technologies. There are the optical system, capacitive system and ultrasonic sensor system in the manufactured sensor to use the fingerprint recognition technology. The optical sensor is the oldest method to capture and compare the fingerprint. The optical system captures the image with CMOS, uses the algorithm to detect the unique pattern such as ridge and valley after analyzing the brightest and darkest part of image and has the advantage of durability and good video quality. The capacitive fingerprint sensor uses the compact capacitor circuit to collect the fingerprint data instead of making the existing fingerprint image. After capturing, you can analyze this digital data to find differentiated and unique fingerprint attributes and save them for later comparison. It is small in size and easy to embed, making it a popular choice for today's smart devices. However, since, it is vulnerable to wet and static electricity, its durability is weak and it is difficult to use in 1:N. Ultrasonic fingerprint sensor technology which is the latest technology, actually consists of an ultrasonic transmitter and a receiver to capture the details of the fingerprint. Ultrasonic pulses are sent to the fingers placed on the scanner to absorb some of the pulse and others to return to the sensor depending on the bumps, pores and other details unique to each fingerprint. We are not yet able to enter the commercialization stage with the technology of 2D data input in 3D and the high price. Figure 1 describes each sensor input technique. All three typical systems can implement the performance through the algorithm for fingerprint recognition. The state of the first input image makes the most effects on the performance of fingerprint recognition algorithm. If the state of the input video is good, the extraction is good if not, the extraction accuracy is low (Maltoni *et al*., 2003; Kim *et al*., 2008; Jung, 2016; NIST., 2004).

The common problem of the fingerprint sensor technology is that the image of poor quality frequently occurs in the dry or wet environment. Even if the capture method of each sensor is different you can check that the image quality is normally poor due to various conditions such as dry skin, the characteristics of the worn finger surface, the poor contact between the finger and the sensor, bright light around the sensor and wet of the sensor (Olsen *et al*., 2015; Zhou *et al*., 2009; Thivakaran *et al*., 2016). In this study, we propose the optical fingerprint sensor which can improve the cohesion and blackening between ridge and valley when capturing the image of wet fingerprint which is the biggest problem

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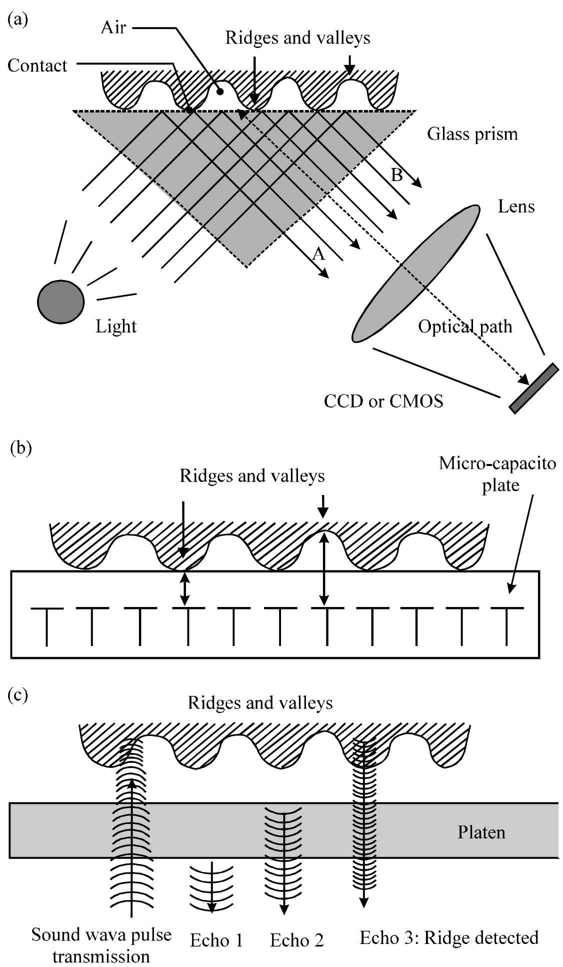


Fig. 1: The fingerprint capture system using the optical system: a) Optical System; b) Capacitive System;c) Ultrasonic System

of optical sensor suitable for unspecified (1:N) and industrial applications. Also, it can obtain the uniform fingerprint image quality regardless of normal and wet conditions.

MATERIALS AND METHODS

The proposed optical fingerprint sensor design: Maximum length of study is 20 pages including the Arabic summary. Extra pages up to a maximum of 5 pages will be at additional extra charge. The margins in all pages except the first page are 3 cm from the top and bottom and 2.5 cm from the left and right. Only the first page should have margins 5 cm from the top, 3 cm from the bottom and 2.5 cm from the left and right. Text should be justified to the left and right margins.

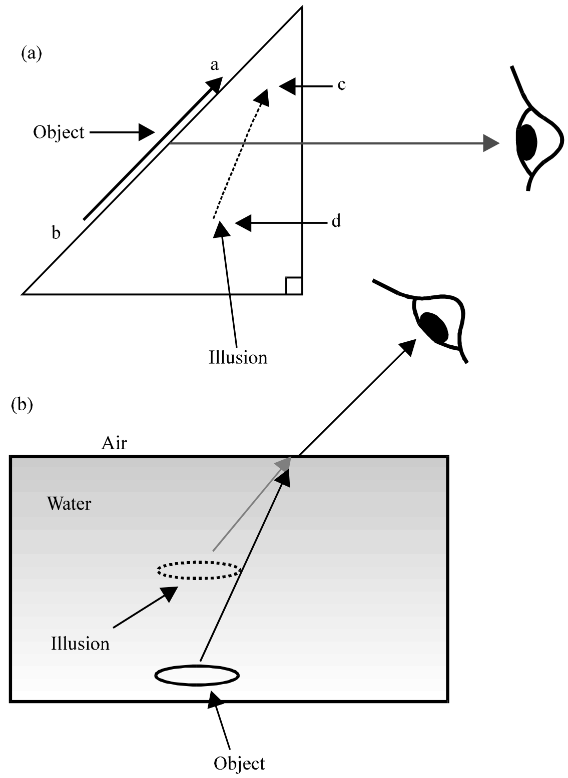


Fig. 2: The principle and understanding of the prism: a) The principle of triangle prism and b) Principle explanation through the object in the water

To design the optical sensor, you should consider the correction of rectangle distortion and trapezoidal distortion. When a prism is applied to an optical sensor, the user does not see the fingerprint on the surface of the prism but looks at the image formed inside the prism. As Fig. 2 when the fingerprint is placed on the surface of the prism, the observer sees c, d, not a, b. This is like an object in water appearing to be in a thin place. Due to this virtual image, the user's eye or lens sees a shorter object in the vertical direction than the actual object length, so that, the square of the prism surface becomes a short rectangle in the actual vertical direction.

There are the optical and software methods to correct the distortion of rectangular. To optically correct the distortion of rectangular there are methods of using a plural prisms and aspherical lens. However in this case, the volume increases and the mass productivity decreases, so, most rectangle distortion is corrected by software. Next, the distortion occurring in the prism is the trapezoidal distortion. As Fig. 3 when attaching the square pattern on the fingerprint surface of the prism, the image formed by the optical path becomes trapezoidal. In this case, b is shorter than a, so, the resolution (dip) is low. When there are

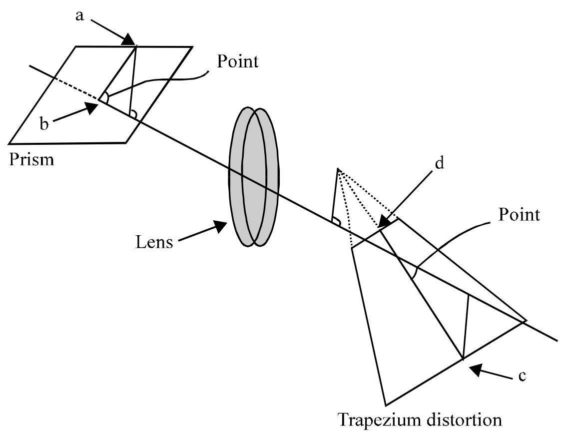


Fig. 3: The trapezium distortion in the prism

trapezoidal and rectangular distortion together, it is difficult to satisfy the resolution (dip) without losing the information.

Therefore, it is important to optically correct the trapezoidal distortion. Until now, I explained the distortion formed when using the prism. The distortion occurs by other lens. This can be attenuated by using a plurality of lenses. In this study, we design the prism in order to obtain the fingerprint image even if there are the water and sweat. As Fig. 4, the incident light from θ_i is refracted to θ_t at the interface of the medium. So, at the angle larger than θ_t, we cannot see the image above the boundary. For example if n_i is water (sweat) and n_t is the prism, we cannot see the water image at the angle more than nt.

Therefore as Fig. 4, it is available to obtain the pure image even if there are water and sweat on the hands when setting the prism angle and lens axis. For low price and performance, the material for prism is selected as SF4. In this design, the method to calculate the refractive index that the water is not seen is same as Eq. 1:

n_i (water refractive index) = 1.33
n_t (SF4 refractive index) = 1.755
n_i: $\sin\theta_i = n_t$: $\sin\theta_t$
$\theta_i = \sin^{-1} n_i/n_t = 49.29°$
$\therefore \theta_i > 49.29°$

Therefore, the prism is available when the start angle is more than 49.29° in SF4. In this study, it is designed as 60° and Fig. 5 is the proposed design.

In addition to evaluate the proposed design of the prism, the optical path design verification is executed through Modulation Transfer Function (MTF) graph. As a result, we checked that it satisfies 100 line in the modulation 30% as Fig. 6.

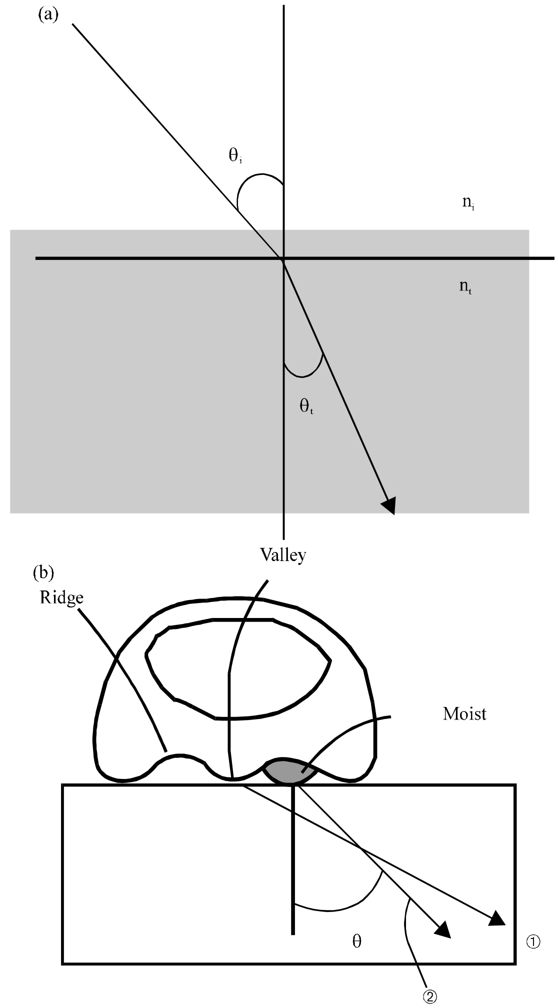


Fig. 4: The proposed design principle of the prism: a) The refractive index of the prism and b) The input of fingerprint and wet through the prism

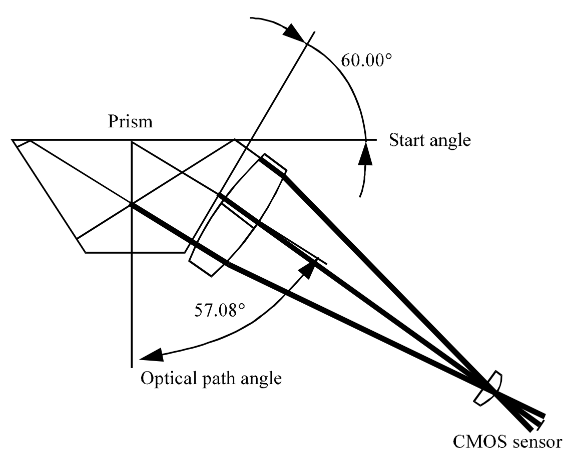


Fig. 5: The proposed prism design

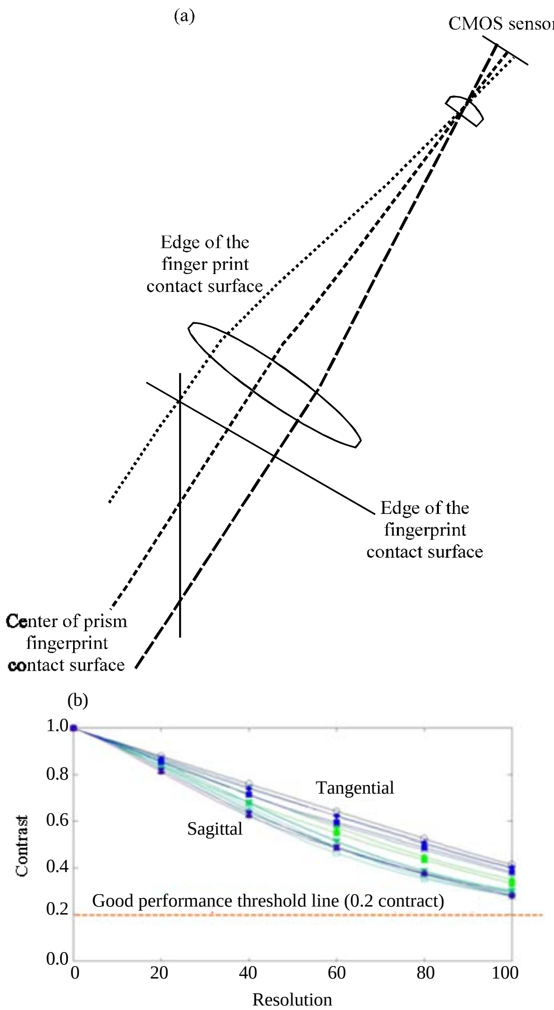


Fig. 6: MTF performance graph about the optical path design: a) The proposer optical system lay out and b) Results of optical layout design simulation MTF graph

In case of the optical sensor to use the prism there is a problem to minimize the image in vertical direction. To solve this problem, the virtual image generated in the prism maximizes the minimized vertical direction by G1 lens and makes the secondary virtual image. And then G2 lens should be imaged on the image sensor (Fig. 7).

Finally, the proposed prism design and lens design are designed by optical path through OSLO. The natural light enters the prism as it goes under the external light shield and the design is completed, so that, it does not enter the G2 lens and does not affect the final image. Figure 8 shows the final sensor design using the proposed prism and spherical lens system when the input area is 25×20.

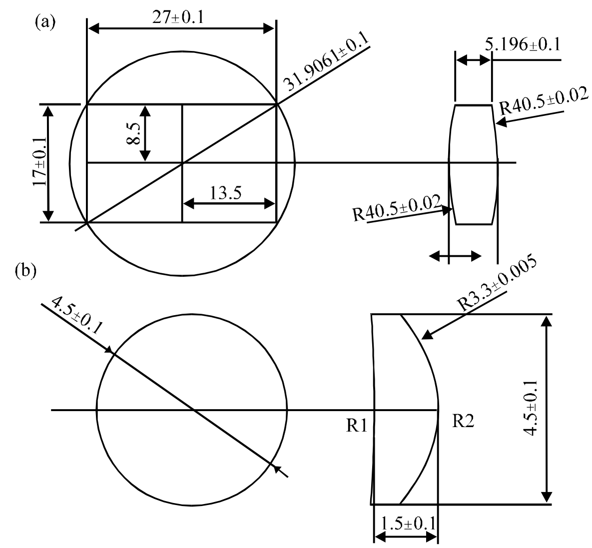


Fig. 7: The drawing of G1, G2 lens design: a) The drawing of G1 lens design and b) The drawing of G2 lens design

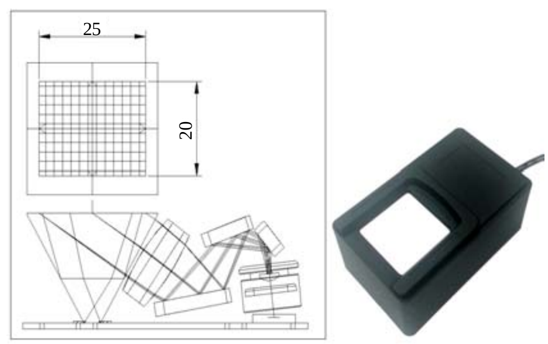


Fig. 8: The final design drawing for the fingerprint input area (25×20)

RESULTS AND DISCUSSION

To verify the performance of the proposed optical sensor, a comparative experiment was conducted by using a commercialized product, NITGEN's optical fingerprint sensor (Model: HFDU06S) and the proposed sensor. To obtain the fingerprint for experiment, a user used 2 sensors, NITGEN optical fingerprint sensor and the proposed sensor. Also, we used the wet fingerprint created by providing the fingerprint status and wet. For experiment, we entered the actual fingerprint and measured the quality of input image through NIST Fingerprint Image Quality (NFIQ) algorithm. NFIQ is a tool for measuring fingerprint image quality, based on open source software and used today to ensure quality in the fingerprint industry in the united states and around the world (Olsen *et al*., 2012; Aabrandt *et al*., 2012).

Table 1: NFIQ grade table

Quality	Index score	Quality grade
0	100	Excellent
1	80	Very good
2	60	Good
3	40	Fair
4	20	Poor

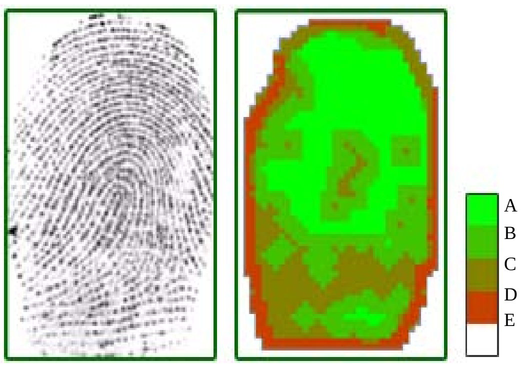


Fig. 9: The definition of NFIQ MAP

NFIQ is divided into 5 grades as shown in Table 1. The quality map showing the details of the quality gives the quality grade and color as shown in A, B, C, D and E in Fig. 9 for 8×8 block size.

The definition of detail grade in Fig. 9 can be divided into A (good quality), B (good quality with low flow/high curve neighbor), C (low flow or high curve), D (low flow or high curve) and E (low contrast or no direction). Figure 10 showed the normal fingerprint images and NFIQ maps that captured using the general optical sensor (HFDU06S) and the proposed optical sensor (Experiment 1).

When analyzing the results of the first experiment, it was confirmed that NFIQ analysis of both sensors showed excellent quality results in case of normal fingerprint condition. The second experiment is conducted with the wet fingerprint to conduct experiments using the same experimenter and experimental method as the first experiment.

Figure 11 showed the wet fingerprint images and NFIQ maps that captured using the general optical sensor

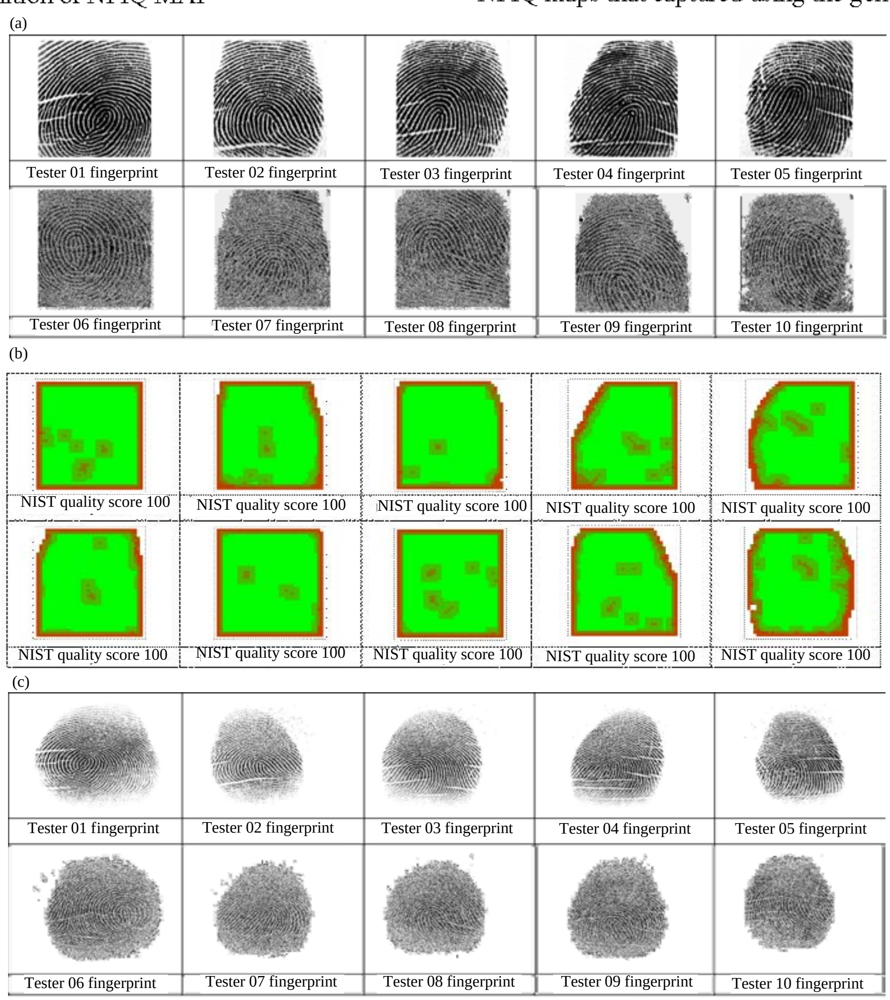


Fig. 10: Continue

(d)

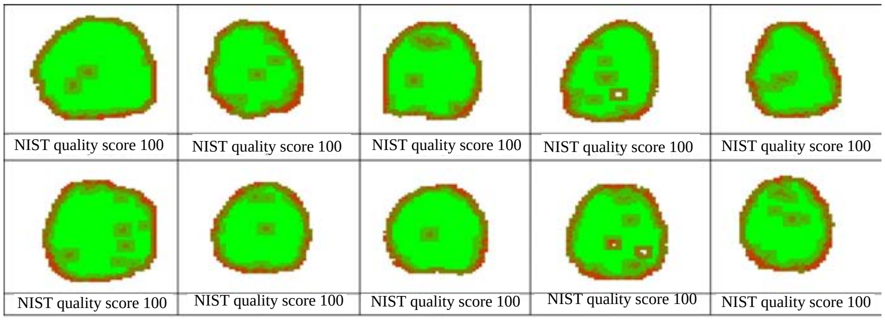
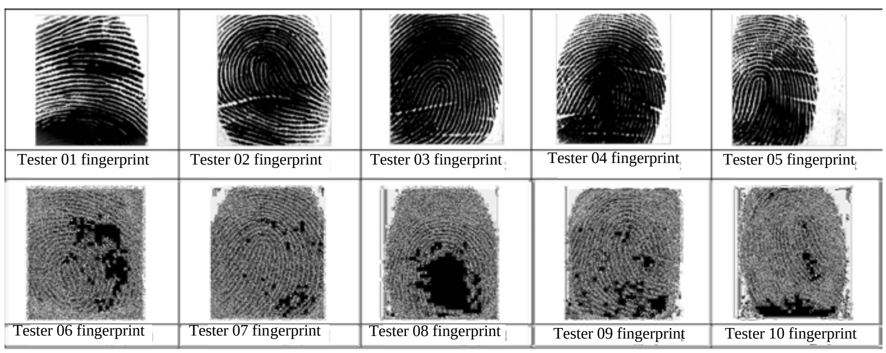
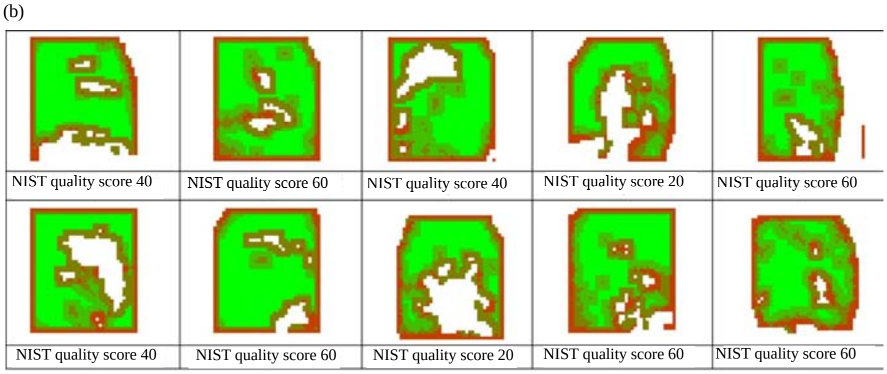


Fig. 10: The normal fingerprint image using the proposed optical sensor and HFDU06S optical sensor and NFIQ result: a) Wet fingerprint image acquired with HFDU06S optical sensor; b) Results of (a) quality analysis of and NIST quality score; c) Wet fingerprint images acquired by the proposed sensor and d) Results of (c) quality analysis and NIST quality score

(a)



(b)



(c)

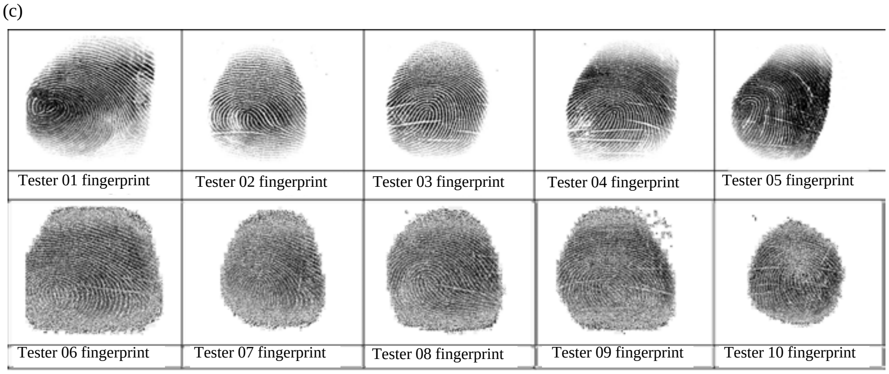


Fig. 11: Continue

(d)

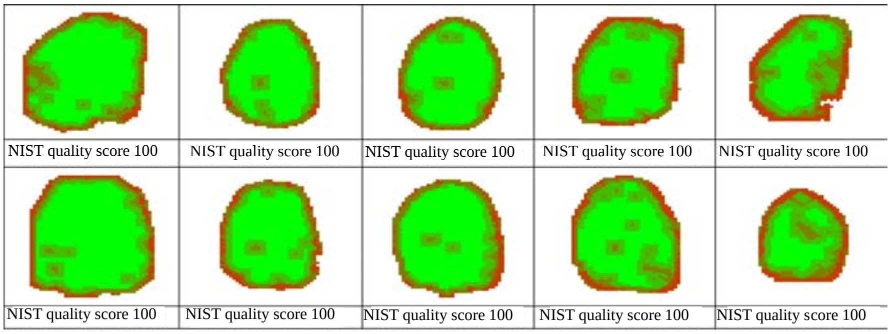


Fig. 11: Wet fingerprint images and NFIQ results: a) Wet fingerprint image acquired with HFDU06S optical sensor; b) Results of (a) quality analysis of and NIST quality score; c) Wet fingerprint images acquired by the proposed sensor and d) Results of (c) quality analysis and NIST quality score

(HFDU06S) and the proposed optical sensor. In the second experiment, the average of 46 score in the existing sensor was lower than that of fair in terms of darkening of the valley area which is characteristic of the wet fingerprint and bunching of the fingerprint area. However, the proposed sensor showed good quality due to the proposed technology that does not react to wet (water, sweat) filled between the valley and the valleys, only the ridge part enters through the treatment of wet.

CONCLUSION

In this study, we propose the optical fingerprint sensor that prevents the fingerprint quality deterioration and has the good quality when you wash your hands right before, sweat occurs in hot weather or there are lots of wet on your hands such as swimming pool, bathroom, etc. A powerful optical fingerprint sensor for the proposed wet fingerprint was designed by calculating the refraction which is not influenced by the wet between the ridges and the valleys through the study of the optical prism design technology and by adding the G1 and G2 lens design for distortion correction, geometric distortion was corrected. Through the simulation, we checked the excellent quality grade results through fingerprint image and objective analysis through analysis of NFIQ. This sensor is expected to be very effective when applied to the optical sensor market.

RECOMMENDATION

In the future, it will be necessary to further improve the environment through further studies and experiments on environments with pollutants other than water, sweat and water.

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