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Fingerprint imaging of dry finger using photoacoustics

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Abstract: Fingerprint imaging has been widely used in biometric identification systems. This work presents a photoacoustic (PA) fingerprint imaging system that provides acoustic resolution using a pulsed laser and focused ultrasound transducer operating as a receiver. This PA system can measure dry fingers with a wide-range laser field based on the differences in the ultrasound coupling between the fingertip areas contacting and not contacting a solid plate. To demonstrate and validate the image accuracy of the PA system, PA fingerprint images were compared to images captured using a pulse-echo ultrasound system and an ink-pressed fingerprint scan.

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1. Introduction

Over the past decade, various biometric technologies have been utilized for identification systems,[1] such as palm prints,[2] retina recognition,[3] hand geometry, and fingerprint identification techniques. Biometric identification methods have also been used for public security systems and criminal investigations.[4] Fingerprint methods are one of the important biometric identification methods because of their ease of use, requiring the user to simply place a finger on a touchscreen for a few seconds. In addition, they have a low misrecognition rate because fingerprint stream patterns possess unalterable characteristics.[5] Recently, fingerprint methods requiring small storage space have been applied in small devices such as mobile devices and laptops as an alternative to personal passwords, which have poor reliability.

Fingerprint imaging methods can be divided into optical and non-optical methods. Optical fingerprint imaging involves the measurement of the differences in reflection between the ridges and valleys on a fingerprint surface. This optical method has a very high resolution; however, it is not well suited for compact system manufacturing because the optical system has to include an optical path and other equipment such as prisms and lenses.[6,7] In contrast, capacitive fingerprint imaging involves the measurement of the differences in capacitance over a fingerprint surface.[8,9] It has been used in small devices such as smartphones and laptops, but exhibits a poorer resolution than the optical method. In addition, ultrasonic fingerprint imaging from the differences in reflection signals in pulse-echo ultrasound systems has so far required immersion of the fingerprint to acquire high-resolution images.[10–12] Until recently, the technology that can use a transmission layer less than 1 mm has utilized the capacitive and ultrasound methods.[13,14] The ultrasound method requires sensitive transmitting and receiving transducers due to the pulse-echo technique, and the capacitive method requires a high-voltage pulse or complex electronics for the transmission. Conversely, photoacoustic (PA) systems require a sensitive receiving transducer because ultrasound is generated by light.

2. Method

Motivated by PA medical imaging systems, the PA method is herein investigated for fingerprint imaging. The PA method generates ultrasound from infrared rays to ultraviolet rays, and any wavelength of light can emit ultrasound waves from the skin as

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long as it meets the laser safety standards. In the system investigated, a light source with a wavelength of 532 nm emits ultrasound echo signals of a specific frequency and is directed onto the epidermis and dermis on the end of the fingertip. The ultrasound signals are measured by a 25-MHz immersion focused transducer operating in the reflection mode. The fingerprint is then imaged using the amplitude differences of the acquired PA signal between the ridge and valley portions of the fingerprint. The PA fingerprint images are compared with the images acquired using the ultrasound and ink pressing methods.

For PA imaging based on laser excitation, it is clear that the acoustic signal arises from thermal expansion caused by the laser light. In the case of medical imaging, multimodality imaging is implemented by sensing the differences in the expansion proportion between tissues. Herein, we present a new fingerprint imaging method based on PA imaging. The key feature of this method is the measurement of ultrasound excitation generated by the laser irradiation of the finger surface. The fingerprint is divided into protruding ridge and hollow valley sections, the latter of which has small air gaps. Ultrasound waves are generated from the surface of the fingerprint (Fig. 1). Where a ridge touches the acrylic plate, the ultrasound response is transmitted to the transducer though acrylic and water media. The measured acoustic pressure from ridge and valley is 2.34 and 1.12 kPa, respectively, with the light intensity of 3 mJ/cm^2. The transduction ratio is comparable to a previous work[15] (80 mJ/cm^2, 100 kPa). In this process, the dominant mode of acoustic loss is from reflection loss arising from the impedance mismatch between the acrylic and water. Contrastingly, the ultrasound waves generated from a valley, which has a small air gap, are transmitted to the transducer though the air gap as well as through the acrylic and water media. In this case, the coupling in the air gap leads to the attenuation of most of the ultrasound energy. Attenuation via the air gap is the crucial process allowing ridges and valleys to be distinguished from each other. Thus, the method proposed here combines PA imaging with acoustic impedance imaging.

The acrylic plate is mechanically supported to allow it to withstand the pressure of a pressed finger. To widen the laser beam to allow coverage over the whole finger on top of the acrylic plate, the laser radiation source is refracted by a convex lens (Fig. 1). The laser angle of incidence of our system is 60°. The angle of incidence in the PA fingerprint system is irrelevant as long as the proper illumination energy is provided. A 25-MHz imaging focused transducer sensitively detects the ultrasound

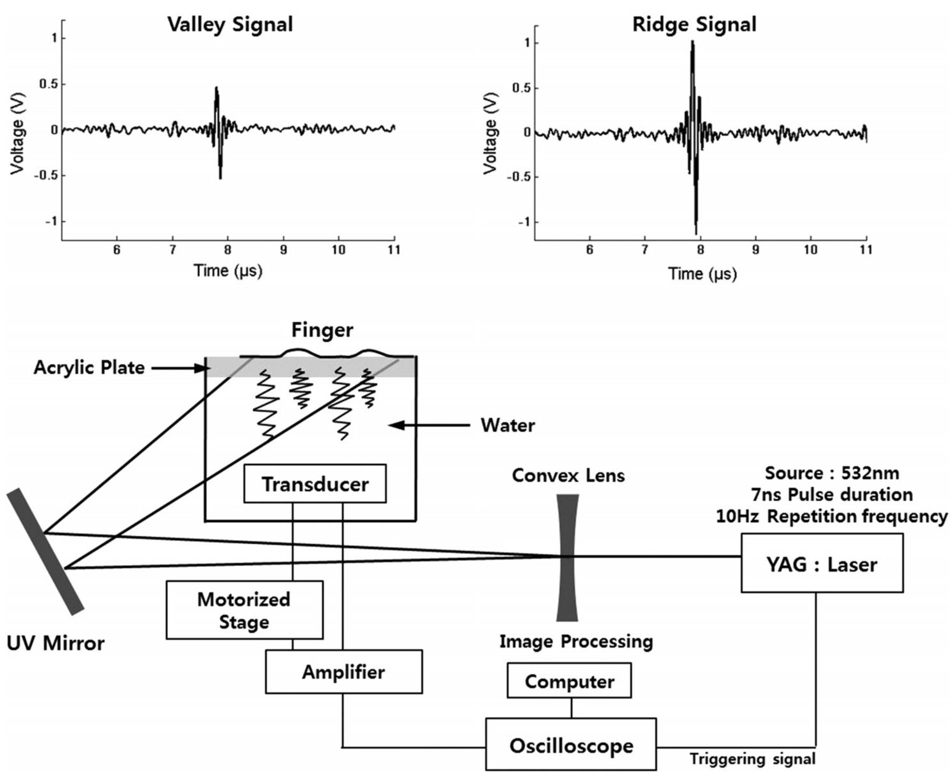

Fig. 1. Overall configuration of PA system and ultrasound signals generated from valley and ridge portions of fingerprint.

pressure from the surface of the fingerprint. The laser light pulses that were used had a wavelength of 532 nm, pulse duration of 7 ns, and pulse repetition frequency of 10 Hz. The laser intensity was less than 3 mJ/cm^2, lower than the safe use limit of 20 mJ/cm^2 (ANSI Z136.1). Ultrasound pressures were detected by a 25-MHz transducer (V324-SU, Olympus Inc., Tokyo, Japan), which has a 12-mm focal length, 6-mm diameter, f-number of 2, and a 34% fractional bandwidth when only used as the receiver. The ultrasound signal was amplified to a gain of 40 dB and filtered by a pulse amplifier (5072PR, Olympus Inc., Tokyo, Japan) equipped with a 1-MHz high pass filter. The resulting signals were acquired and stored using an oscilloscope (DSO1014A, Keysight Technologies, Santa Rosa, CA). A motorized control stage (SM3-0820-4S, Sciencetown Inc., Daejeon, Korea) with μm-scale resolution was used for the area scanning by applying repeated movements of equal distance.

As the main portion of this work, we conducted feasibility testing of the proposed fingerprint imaging system for single-shot PA imaging including laser illumination of the entire fingerprint area. The ridge and valley portions, i.e., the skin–acrylic and skin–air–acrylic media, could be distinguished from each other by the amplitudes of the received ultrasound (Fig. 1). In this setup, as the imaging was conducted with the irradiation of the entire object, the fingerprint images had to be constructed from the acoustic resolution data. As shown in Fig. 2, to quantify the lateral resolution of the PA system, the resolution data were extracted using a resolution chart [1951 United States Air Force (USAF) resolution chart]. In the ink print target, the rate of light absorption and the intensity of the acoustic signal are higher than that for the skin. However, the resolution test is an experiment to measure the lateral resolution of this system, and it is compared with the theoretical lateral resolution. The resolution chart sample was fabricated by a photomask process, which has a 30-μm print resolution. The resolution chart was imaged using the same concept used for the PA fingerprint imaging. The focused transducer has a 120-μm theoretical lateral resolution based on the f-number, wavelength (60 μm), and 88-μm theoretical axial resolution. Fingerprint imaging is dependent on the lateral resolution due to the imaging of the finger-coupled surface. The resolution target was imaged using 13-dB dynamic range image processing [Fig. 2(b)]. The experimental results indicated a system acoustic resolution of less than 280 μm. Because the pitch of a narrow stream line in a fingerprint is 400 μm, this resolution is sufficient for distinguishing a fingerprint.

3. Results

To compare the PA fingerprint image quality of various methods, the fingerprint image results using the ultrasound and ink-press method are presented. As shown in Fig. 3(a), a fingerprint image is acquired using the ultrasonic pulse-echo signal from the same system used in the present PA fingerprint imaging setup. For transmitting and receiving, an ultrasonic pulser-receiver is used (5072PR, Olympus, Inc., Tokyo, Japan). The principle of the ultrasound method is to use impedance mismatching between the ridge portion coupled to the acrylic plate and the valley portion separated from the plate by an air gap. In this method, the reflection signals from the valleys are stronger than those from the ridges because the air–acrylic impedance difference (in the valley) is larger than the skin–acrylic impedance difference (at the ridge). The image displayed in Fig. 3(b) is sufficiently detailed to allow the fingerprint stream lines to be

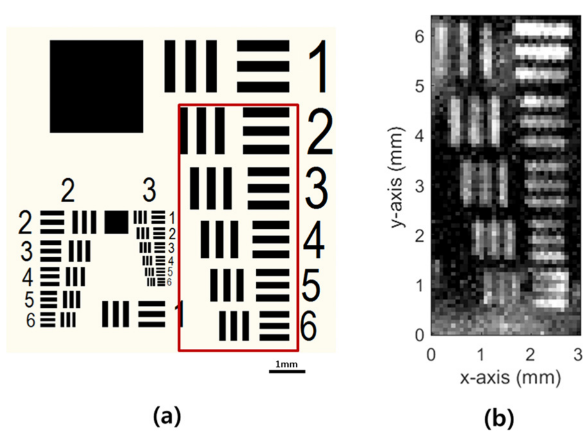

Fig. 2. (Color online) (a) United States Air Force (USAF) 1951 resolution chart and (b) PA image of chart portion reproducing the area indicated in (a).

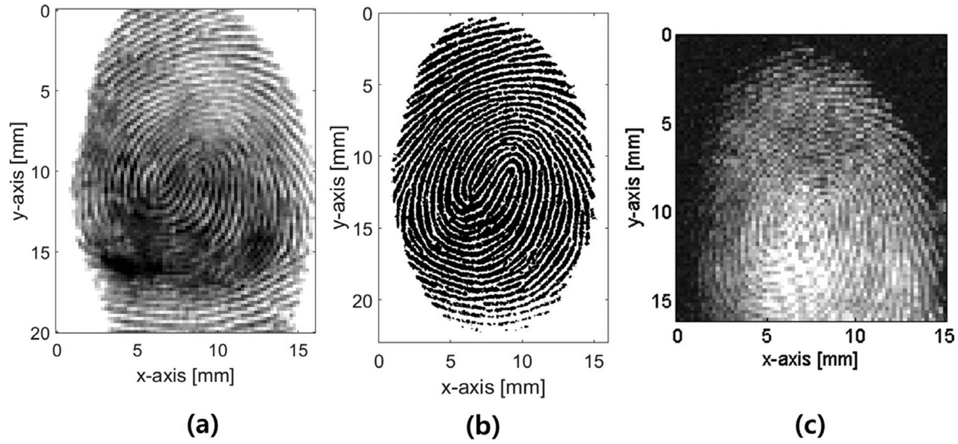

Fig. 3. Fingerprint images measured by (a) ultrasonic pulse-echo impedance mismatch method, (b) ink-press method, and (c) PA method.

distinguished, and includes a 600-dpi scan of a fingerprint image collected using the ink-press method. As shown in Fig. 3(c), a fingerprint image was acquired by the PA system, and the PA image quality is worse than that obtained by the ultrasound method because previous PA imaging systems image soft tissue using the expansion rate difference. However, this system was imaged by the coupling of hard material and skin. The PA image was sufficiently detailed to allow the fingerprint pattern to be distinguished. The signal intensity of the PA imaging is proportional to the intensity of the light source. Therefore, the observed non-uniformity in the Fig. 3(c) image arose from the non-uniformity of the light source, originating from one of the convex lenses used.

4. Conclusions

We have investigated the use of the PA imaging method for fingerprint imaging. The fingerprint images were acquired in dry conditions using a PA system consisting of a focused transducer and a diffuse 532-nm laser source. As light radiates over the whole finger, the acoustic waves of the PA fingerprint imaging system are generated as a single shot. An array transducer allows the received acoustic signal to be received in a single shot.

Previous ultrasonic fingerprint imaging methods required high-voltage pulser electronics for the pulse-echo imaging. However, in the present PA system, due to the generation of ultrasound at the fingerprint surface by pulsed laser irradiation, it only has to receive the ultrasound signal. The factors limiting the resolution of this system are the intensity difference according to the gradient of the light, the noise level, and the acoustic coupling varied by finger pressure. In order to commercialize this system, the light needs to be provided by a semiconductor light source located between the receiving transducer array, or a light-guided plate needs to be used.

Acknowledgments

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