Development of ultrasonic finger reader based on ultrasonic holography having sensor area with 80 mm diameter

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Abstract: This paper describes finger reader, that generates a fingerprint image using ultrasonic waves travelling parallel to the sensor surface in concert with the principle of acoustic holography. The idea realized in this unit allows for the creation of devices based on thin plates of varying sizes, from smaller than a postage stamp, to the largest live scan applications that can be integrated with typical touch screens. The device is able to recognize the type of material that comes into contact with sensor surface, allowing it detect features consistent with living fingers and, therefore, differentiate between live and fake fingerprints. The sensitive sensor plate, or platen, used in the device can be constructed from a variety of different solid materials, such as glass and metals. The transducers are placed on the rim of the sensor plate The working principle of the device is based on the directions of ultrasound waves and not on pixels, hence the complexity of the device does not depend on the size of the sensitive area. Achievable resolution can be much higher than necessary for finger recognition. The device referenced in this presentation achieves resolution that is comparable to 1000 dpi.

Keywords: Finger recognition, ultrasonic holography, live finger recognition, touch screen, liveness detection

1 Introduction

The fingerprint reader described herein is based on practical experience collected during the previous work over several years, with results that were published in previous papers and disclosed in patents. This has led to the creation of prototypes based on the same fundamental concepts, but with the ultrasonic transducer moving in water filled containment. The summary of this work is given in [BB99]. The first patent was granted 1990 (US Patent 4,977,601, application submitted in 1986). It was the first proposal to use ultrasound as a scanning medium for fingerprint recognition.

All ultrasonic fingerprint readers are based on the fact that sound waves travelling in solid sensor material are scattered by areas of the finger's skin that is in contact with the sensor surface. This is referred to as contact scattering, which is also similar to the effect observed with light waves. A small fraction of sound energy is transmitted into the finger, another fraction is scattered in form of different wave modes in all directions, as

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allowed by the device configuration. A large part of sound wave is reflected, as with our previous devices, or is propagating unchanged, as in the device described herein.

2 General principle of the picture creation in the holographic ultrasonic finger reader

There are many possible applications using ultrasound for fingerprint recognition, such as the use of focused sound and mechanical movement, direct comparison with acoustic hologram (as described in the first patent, cited above), phased array technique instead of mechanical movement, or the application of many small transducers in close contact with the skin.

The device described in this paper and also in the paper [WB1] is a holographic camera – it utilizes the coherence of sound waves and the fact that in acoustics, there is no need for a reference beam as is the case with optical holography; an electronic reference is sufficient. Fingerprint ridges (or feature attributes with any other object) can be treated as a superposition of many diffraction gratings with different vectors K (see fig. 1) and described by f(x,y). The amplitude A of each component can be obtained by using a two-dimensional Fourier transform and the distribution of diffracted acoustic field represents the unequivocal pattern of fingerprint surface ridges on which the diffraction occurred.

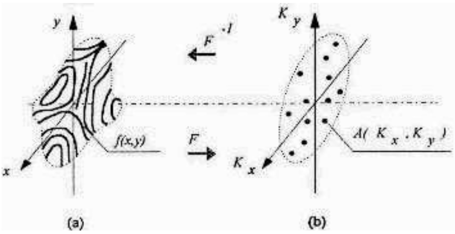

Fig. 1 Basic principle of the acoustic holography method

Following formula describes the result:

$$A(K_x, K_y) = F[f(x,y)] = \frac{1}{4\pi^2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)\, e^{-i(K_x x + K_y y)}\, dx\, dy$$

It is Fourier transform (Fourier hologram) of the fingerprint ridge structure. The same result could be obtained directly if the device used bursts with different frequencies. However, the use of short (broadband) ultrasonic pulses is simpler and improves significantly acquisition speed. This approach allows the device to deliver a pulse solution for a portion of the fingerprint. The full fingerprint image is comprised of a collection of pulse responses, or solutions, from different directions - signals obtained from each direction surrounding the finger, or target object, contains the necessary information used to describe the complete fingerprint, or whole object. To be able to achieve the required fingerprint image accuracy, or resolution, it is only necessary to collect pulse responses (solutions) from a sufficient amount of directions surrounding the sensor surface, and to use ultrasound waves with a short enough to match the distance between fingerprint ridges. It is a very important to note that the method used to define image resolution here is **not derived from the number or density of pixels. Instead, the image resolution is determined by the number and direction of pulses generated by the sensor plate.** Naturally, it would be possible to use a direct pulse response/solution (or Fourier transform) for further object comparison or evaluation. However, because people are more accustomed to working with geometrical finger representations, after signal acquisition the reconstruction of the geometrical picture is performed, the device uses back projection algorithms, such as those applied in tomography (other algorithms are possible too).

3 The feature of ultrasonic reader

The features described above result in an increase in the active sensor area without requiring changes in the electronics or in the number of ultrasonic transducers used; Instead, this approach only increases the time required for signal acquisition. Moreover, since the resultant increase in tine required is only microseconds, even for large surfaces, it is possible to create fingerprint reader devices with large size sensors, or scanning surfaces, that will operate in real time. Construction of the finger reader

The fingerprint reader device being described contains basically two parts: Sensor plate with ultrasonic transducers (small piezoelectric plates) positioned around the to its rim and electronics, that contain a multiplexer and the evaluation circuit, with an ADC and processor for multiplexer control, picture preparation and analysis.

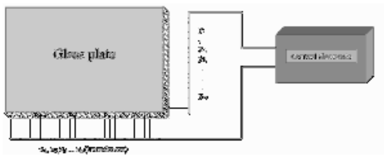

Fig. 2 Schematics of ultrasonic finger reader

The existing prototype version contains a round plate with 100 mm diameter and a sensitive surface area of around 80 mm, since this version of a prototype device was easier to build. A similar prototype device containing a sensor surface that is a square plate with small thickness is now in preparation.

The device uses short SH (shear horizontal) wave pulses, propagated parallel to the sensor surface, with a bandwidth of around 5 - 12MHz. It features 256 transducers (directions), which allows the device to achieve a resolution comparable to around 1000 dpi. To achieve this resolution, it was necessary to develop and build a special multiplexer. For signal acquisition in first prototypes, an OPBOX manufactured by PBP Optel was used, while upgraded, mobile versions of the fingerprint reader incorporate specially developed electronics. The development of this device was based on previous work. However, it was necessary to create many sensor plates, in order to master the technology required for transducer attachment. Mastering this technology was critical for the proper functioning of the resultant ultrasound reader device. The first working prototype of this device contains signal acquisition electronics with a size of 169x 82x 150mm, as depicted in Fig. 3:

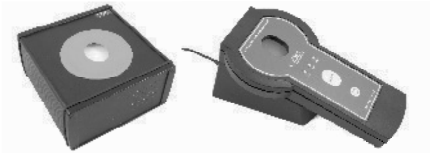

Fig. 3 Prototype of ultrasonic holographic camera for finger recognition; Mobile version.

This prototype device is connected to a PC via USB interface. Picture evaluation and fingerprint recognition is processed using the PC software. The resultant fingerprint reader device is able to scan and process a single image of a fingerprint at a rate of one per second. After building several of these prototype =, a mobile version of the prototype was developed. The mobile version of the prototype (depicted in Fig. 3) uses the same sensor plate, but contains the electronics required for signal evaluation. In addition, the battery is smaller and is connected to the PC via a Bluetooth interface.

4 The pictures of ultrasonic reader

Pictures obtained with ultrasonic holographic finger reader as stated above, a direct approach to developing the capabilities delivered by the prototype device described above would employ a pulse solution. A typical example of this pulse solution for a fingerprint is illustrated in Fig. 4. The pulse response generated for each direction is represented with one vertical line, where the amplitude of the signal is shown in gray scale. In ultrasonic techniques this is typically known as an A-scan response, while the whole picture above would be described as B-scan solution.

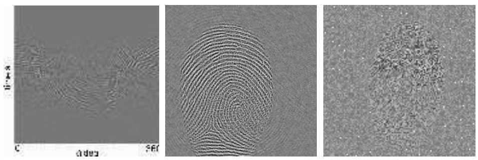

Fig. 4 Pulse answer, reconstruction, obtained with holographic finger reader

After the reconstruction of the fingerprint image using all of the pulse solutions generated by the transducers along the rim of the sensor plate is provided by a geometrical representation of finger print, as shown in Fig. 4. The evaluation of quality of images, obtained with the device was conducted according to standards, created by such biometric projects as US-VISIT, PIV (personal identity verification), PassDEÜV and CNIPA-A /B /C. Following image quality features was quantified [CF08] [AC08]: acquisition area, native resolution, output resolution, gray level quantization, resolution accuracy, geometric distortion (input/output linearity), focusing (spatial frequency response), signal to noise ratio (snr), fingerprint gray range (dynamic range). IQS parameters of opFinger ultrasonic reader was satisfying according to all above mentioned standards.

5 Significant features of the reader

The prototype device applies ultrasonic SH (shear horizontal) waves, which results in a much stronger signal obtained from real finger than a signal delivered by artificial objects with the same structure, such as fake fingers made from any known material(s) used for such purpose. The reason for this ability to differentiate between a “live” and “fake” finger, seems to be attributed to the constitution of the outer surface of the finger skin (stratum corneum), which is made from a very hard material called dry keratin. Simple experiments with a small diameter object tips, made from materials with different hardness, e.g. steel and plastic, show that steel tips produce a much stronger signal than a plastic tip. Apparently, this feature is also the reason for the fact that a fluid on the sensor surface, such as water, oil or grease, is not visible and does not cause any deterioration of the fingerprint image, as is the case with optical and capacitive resistance readers. In like manner, many other contaminations on the sensor surface that would render optical and capacitive resistance readers useless, are often not visible with an ultrasound reader. Scratches or local damage to a sensor surface that destroy optical and capacitive resistance readers may be visible to an ultrasound reader, but they can be eliminated with the software, since their location and attributes are known and will not change. It is easy to understand why local damage won’t have any influence on the function of the remaining part of the sensor. Since the sensor plate is often made from homogenous glass, or a similar material, only large scale damage to the sensor surface will cause degrade the resultant image to such a degree that the sensor may be rendered unusable.

It can be also demonstrated, that the ultrasonic wave is capable of penetrating the skin to some depth– apparently around 0.5 mm for existing devices. This capability provides very good visibility in comparison to images obtained with a real finger and a detailed, faithful copy of this finger made from silicon or similar material. With images of a real finger, sweet glands are visible when generated by the ultrasonic reader. However, this is not true of images captured of the artificial finger. They are visible when viewed on the surface, but are not visible in images generated by the ultrasonic reader. This indicated an innate capability for the ultrasonic reader to differentiate between “live” fingers and fake fingers. The only realistic explanation of this fact is the assumption, that the ultrasonic wave is penetrating the internal structure of the stratum corneum and reacting with the deeper structure of the finger's sweet glands. Fig 5 illustrates the difference: left picture is obtained from real finger, right from its silicon copy. Sweet glands are visible on the left, not on the right picture, although they are visible on the finger prints of both structures, made with ink. It must be taken in account, that the difference in signal strength is large and is causing additional noise, such as the visible as black points on the right picture.

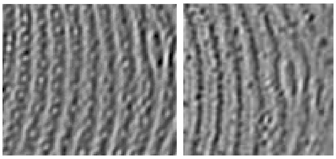

Fig. 5 Comparison of real and artificial finger

Images obtained with holographic ultrasonic finger readers have a number of extremely beneficial functional capabilities and characteristics that are different relative to images obtained with other methods, such as optical and capacitive resistance technologies.

6 Acknowledgements

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7 Conclusions

The devices described in this paper demonstrate the real and potential capabilities associated with the prototype technology OPTEL has developed for holographic ultrasonic finger readers Given the tremendous capabilities associated with this technology, it is clear that ultrasound fingerprint readers employing acoustic holography will not only be very competitive in comparison to all known existing and emerging techniques used for fingerprint recognition, due to the following capabilities:

The sensor plate can be used instead of touch screen and have even quite large dimensions. This is especially interesting for the use in smart phones and similar devices. It must be mentioned, that the functionality of finger recognition is the most sophisticated in this device; it can be also used as touch screen or graphic tableau with extremely high resolution. The device is working even under difficult environmental condition, under water, with dry or oily fingers. The sensor is able to recognize true fingers from any kind of copy and detect many liveness features. It can work in real time, it is even possible to make finger recognition on fly, during typing. The anticipated cost of the sensor in the case of mass production will be very low, since the cost of all necessary materials and elements are low and it is expected, that the device can be made maximizing the use of automation. Given the capability for ultrasound waves to penetrate further into the fingerprint tissue, it is conceivable that a multimodal biometric scanning and processing capability can be developed and integrated within the same device. It is anticipated that this capability can be developed and integrated with the existing ultrasonic reader software, resulting in minimal impact to form factor. Multimodal capabilities: Fingerprint, Palmprint, Finger geometry, hand geometry, vein structure mapping, and pore mapping. Each of these multimodal capabilities represent unique biometric attributes that are specific to each individual. The introduction of Multimodal capabilities will increase the FRR, FAR and potential user population to above 99%x. Product scalability from large live scan devices to small form factor solid state technology that can be integrated into small electronic applications. The latter assumes sufficient investment and startup capital for tooling and to initiate production. It is naturally necessary to continue the work on miniaturization of the electronics and the improvement of the technology of the sensor plate.

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