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ULTRASONIC CAMERA FOR FINGER RIDGE PATTERN IMAGING (*)

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This paper describes the design of an ultrasonic camera with a resolution of 0.1 mm. The camera makes it possible to observe the near surface structures of solid objects and is suitable for finger ridge pattern imaging (i.e. a pattern reflected in the fingerprint). The device can be used for biometric identification of individuals (for access verification). It can also be employed for all other sorts of structures with ultrasonically detectable changes in the near surface structure, both natural and artificial ones (e.g. created for information recording). The paper describes the current version of the camera and the physical basis of its operation. Perspectives of further development of the device are also presented.

1. Introduction

During the last few years a new area of engineering science has been established whose products are likely to create a large market in the near future. It has been called "biometrics". The pioneers of this new domain intend to construct devices which would allow the identification of a person on the basis of his/her "biological" characteristics: voice, dynamics of movements, features of the face and other parts of the body, retina or iris pattern. However, most promising seems to be the possibility of fingertip structure recognition (this structure is reflected in the fingerprint pattern). It is well known that the finger ridge pattern is different for each individual and does not change over the life time. Touching of a sensor surface is a simple act. Many inventors of biometric devices hope to develop a button which would "know" by whom it has been pressed and which finger has been used. The button used for unlocking a door would obviously let in only

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authorized people. Since such a device is likely to find numerous applications, one can envisage a rapid development of the market for biometric devices [1, 2, 3].

Systems for the ridge pattern imaging with optical acquisition of the data have been investigated for a number of years. They show "live" fingerprint images directly from a finger without the need for ink and paper which have been traditionally used by policemen since Galton's times [3, 4]. Systems with optical data acquisition, however, have a number of drawbacks: the direct image of the fingertip is of very low contrast and it is easier to see the dirt on the finger than its ridge pattern. Moreover, methods employing the reflection from a surface are very sensitive to grease, dirt, and water. A three dimensional image is difficult to create and does not provide satisfactory results for damaged fingers [2]. Furthermore, no method allows to decide easily whether the object under observation is a real finger, an imitation, or perhaps a greasy residue of a finger on the sensor. The description of a typical optical fingerprint imaging system is given in [6].

Hence, it should not be surprising that there has been interest in alternative methods of ridge pattern imaging. For instance, Constantine Tsikosa proposed a capacitive method [7], recently developed further by SGS-Thomson [8] and Siemens [3, 9]. So far only prototypes of such devices have been presented and little is known about their practical usefulness.

2. Perspectives of the ultrasonic devices development

In 1986, the author of this paper proposed a method based on the ultrasonic data acquisition [14]. This approach allows to distinguish between real fingers and any imitations. Furthermore, it is not sensitive to any dirt, grease etc. There is also a completely new perspective unthinkable in the case of other methods. It is possible to create a device with a surface reacting to a finger touch (or a number of fingers) which would be able to decide where the finger has been placed, identify it and register its movements. Such a device would not have any moving parts and could replace today's keyboards, mice, graphic pads, and fingerprint identification systems, though these are not all of its potential applications. To complete the picture, it is worthwhile knowing that it is feasible to create a device that is small, inexpensive (a kind of chip), and could really fit in a button. Such a device would have another interesting property. It would enable us to devise a system for remote people identification (through a network) which cannot be cheated, even if a person sitting at a remote terminal has all the technical means to carry out a fraud.

A number of papers have been published describing our method [10–13], a few patents have been granted and a few other patents are pending [14–16] (the owner of the patents and commercial rights to the device is Sonident, Vaduz). This work is aimed at a brief presentation of the key aspects of the method employed by us which have not been described in detail in the previous papers. The paper is also intended to present the subject to the readership of "Archives of Acoustics".

3. Principle of the ultrasonic camera operation

The operation of our devices is based on a phenomenon which apparently has not been employed so far by anyone and, perhaps, not even noticed (to the best of our knowledge). It can be summarized in the form of the following rule:

Consider a surface of a solid object on which another object has been placed, so that the contact between the two objects is not ideal, i.e. there are some inhomogeneities. The sound wave which reaches such a place does not only pass from one environment to the other one, get reflected and diffracted in the contact area as described by the classical theory but it also is subject to some additional scattering and transformation to a different kind of waves. This phenomenon is the effect of a disturbance of the sound propagation conditions in the contact area between the two objects, hence it will be referred to as the contact scattering. It is sure that this kind of scattering results not only from the contact area of the two objects but also from the area near the objects' surfaces (henceforth it will be referred to as the near surface structure). It is likely that for this reason the contact scattering is strongly dependent on the substance of the objects.

Experiments show that the transition of the wave from one environment to the other one may practically not occur at all and only the contact scattering and generation of other types of waves (that is particularly conspicuous for transversal waves) are observed. It is likely that the disturbances of the wave occurring in the contact areas are mainly in phase (the phase front is spatially distorted) and are responsible for the observed contact scattering. At the moment, research aimed at a theory adequately describing this phenomenon is being carried out. We shall devote further publications to this subject.

4. Design of the ultrasonic camera

Employing the phenomenon described in the previous section, we have designed a device for measuring and analysing signals resulting from the contact scattering of objects placed on a plastic window. The device is designed mainly for the near surface observation of the finger ridge patterns. A detailed description of our device has been presented in the aforementioned papers. For all those readers who are not familiar with the subject, we offer a brief description:

An acoustic wave is sent in the direction of the surface on which an object has been placed (see Fig. 6). Signals scattered by the object are received by the transducer (T) that is moving along a circular trajectory whose axis is perpendicular to the contact surface ($x - y$). The same element can be used both as emitter and receiver. Alternatively, it is possible to employ a number of fixed transducers, instead of a single moving transducer.

For the analysis of the object with a resolution of about 0.1 mm, it is necessary to collect the scattered signal data from about 256 different angles. At the moment, our device sends a short pulse in each of the 256 directions and receives the impulse response (in the case of a finger, the signal spectrum is in the range from 4 to 16 MHz and depends on the device design). Figure 1 shows the set of impulse responses for a small ball, whereas

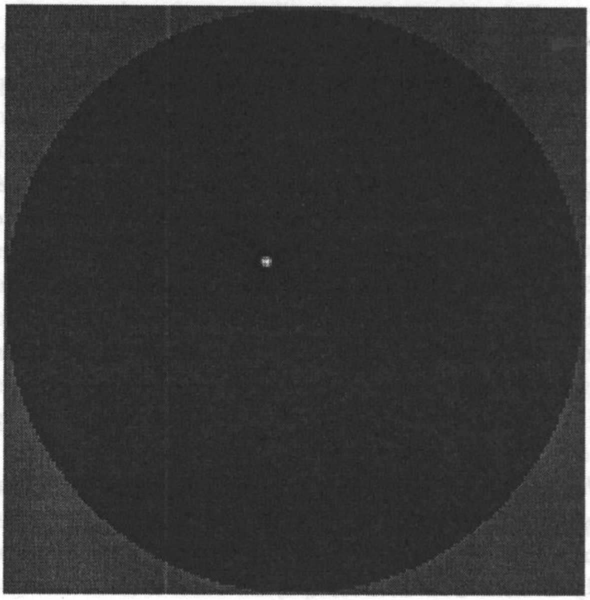

Fig. 1. Reconstruction of a ball.

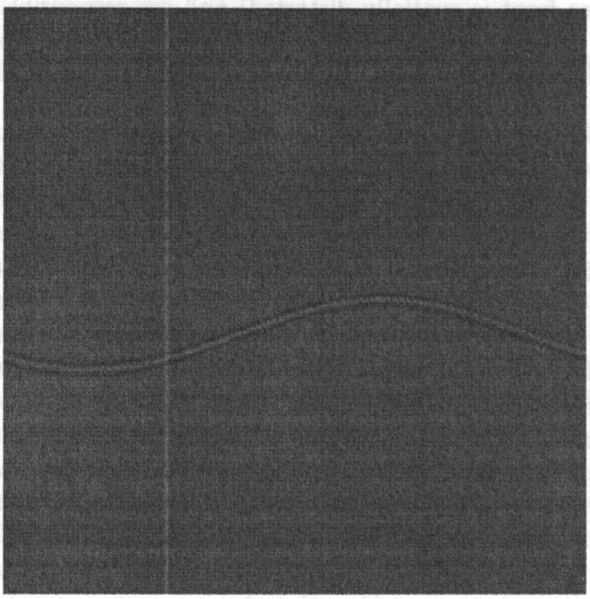

Fig. 2. Impulse response of a ball.

Fig. 3 shows those for a finger (the vertical axis corresponds to time, the horizontal on to the angle, the value of the signal is represented by the grey level). In order to obtain the observed structure from the collected data, a reconstruction procedure is used which

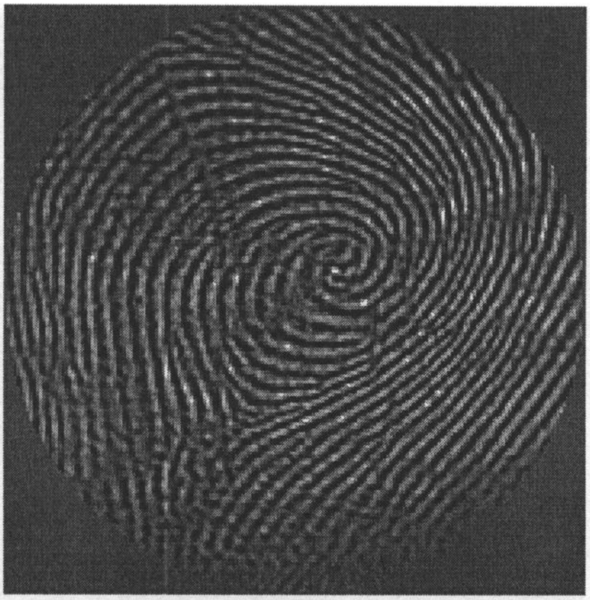

Fig. 3. Reconstruction of a finger.

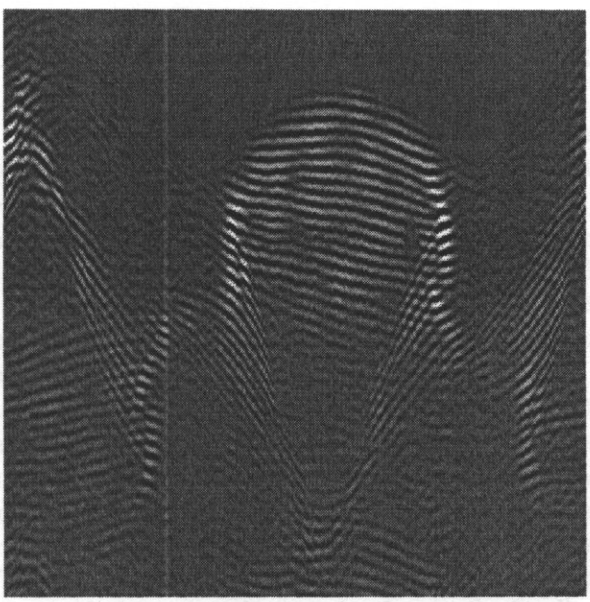

Fig. 4. Impulse response of a finger.

is similar to the methods used in ultrasonic reflection tomography. A set of programs aimed at achieving high quality and high speed reconstruction have been written. The algorithms developed at Optel enable image reconstruction based on a set of 256 impulse

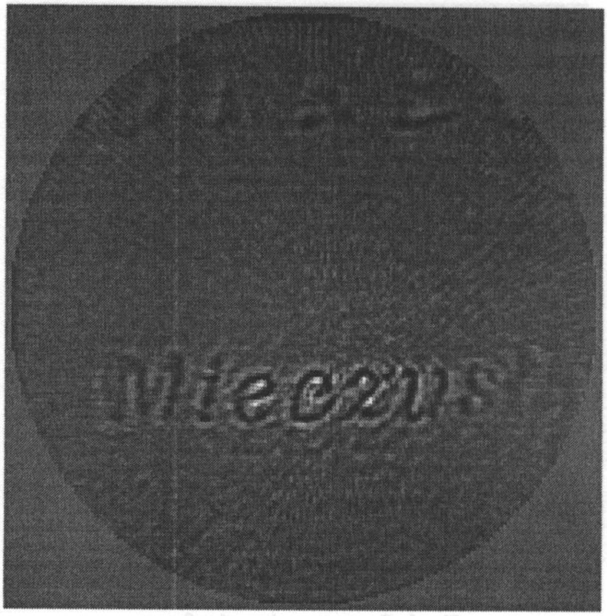

Fig. 5. Reconstruction of a stamp.

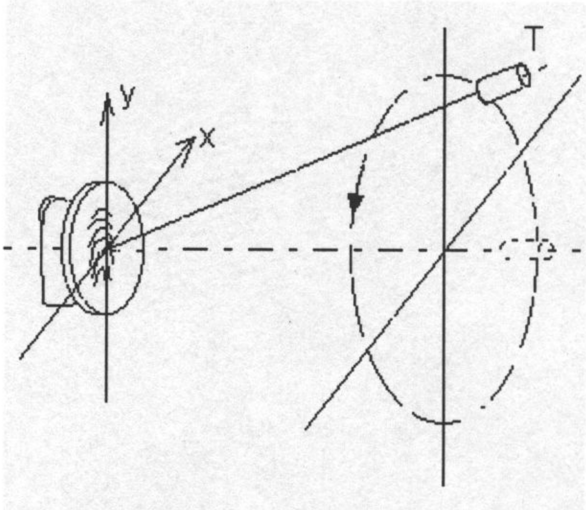

Fig. 6. Schematic diagram of the device.

responses each containing 181 samples in about 20 ms (using a standard PC based on the Cyrix 6x86 P200+ processor). The reconstructions for the impulse response given in Figs. 1 and 3 are presented in Figs. 2 and 4, respectively. Figure 5 shows the image of a stamp placed on the sensitive surface of the device. A photograph of the current version of the device is presented in Fig. 7.

Fig. 7. Appearance of the camera.

5. Technical solutions employed in the camera's design

The use of the contact scattering phenomenon discovered by us and the computer tomography methods were not sufficient to construct an ultrasonic camera. We had to solve a few other problems:

In order to obtain the required resolution, it was necessary to develop a device which, having a relatively small diameter, would emit a gaussian ultrasonic beam of high amplitude and would have a high sensitivity as receiver. A device which meets these requirements has been developed and patented [16]; we intend to present its construction in a separate paper.

It was also necessary to develop a transducer which would be able to emit a short pulse and would have the required bandwidth (4 - 16 MHz) as receiver. Moreover, its phase function was required to have the smallest possible variance. It was also important that such a transducer would be cheap and would have repeatable parameters (the final effect of our research is expected to be a device suitable for mass production at a reasonable price). The researchers at Optel managed to develop a transducer which has a completely new design (a patent application has been submitted). It is able to emit very short pulses (in the range of 20 ns - see Fig. 8) and has a very wide bandwidth as receiver (ca 4 - 25 MHz). The amplitude of the signal emitted by the new transducers is about two times higher than those of classical pulse transducers. Their sensitivity as receivers is however slightly lower giving a comparable result in the measurement cycle. Nevertheless, the idea of those new transducers opens up new possibilities for

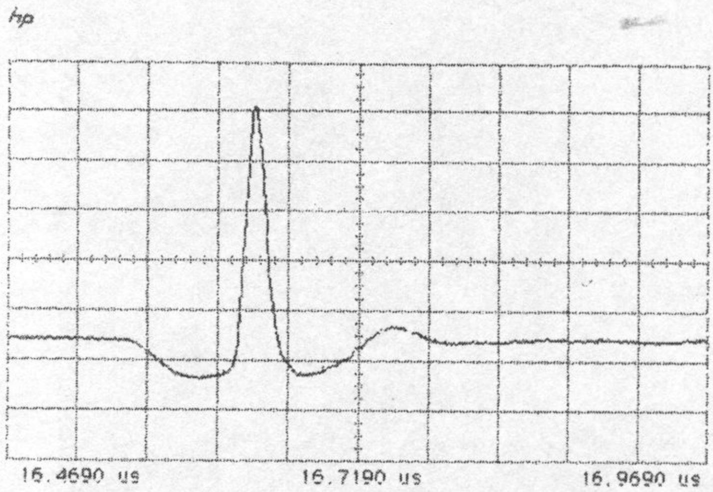

Fig. 8. The shape of a pulse generated by our transducer.

designing ultrasonic transducers and a significant improvement of their parameters can be expected; we wish to devote a separate paper to this subject.

The design of our ultrasonic camera would not have been possible, unless we had not developed our own electronic circuitry which includes the transceiver circuit and an oscilloscope card. These elements are also based on our own original ideas: the pulse generator is capable of generating pulses as short as 20 ns with an amplitude of ca 600 V; the receiver has a sensitivity of 5 μV for frequencies within the range of 4 – 16 MHz, and a dynamic range of 60 dB. The oscilloscope card makes it possible to sample at up to 200 MS/s and is specifically dedicated for processing sets of ultrasonic signals (it satisfies some strict timing parameters).

It should also be noted that our ultrasonic camera would not be of much use if there were no methods for the finger ridge pattern analysis. Also in this area we have some original solutions, though they are perhaps of less interest to the readers of this journal. It is however worthy of notice that the algorithms which have been developed allow not only fingerprint recognition but also a significant compression of the fingerprint data. For example, a finger ridge pattern can be synthesized from the information contained in as few as 100 bytes.

6. Observations with the use of the camera

• Objects of similar structure but made of different substances give significantly different signals (both in amplitude and character). The structure of the objects is nevertheless visible. Hence, it is possible to distinguish between "real" and "artificial" fingers.

• Spreading gel on the surface of an object, soaking it in water or covering with dirt does not cause significant changes of the signal.

• A fingerprint is hardly noticeable because its signal level is at least by 30 dB lower than that given by a real finger (in contrast to this, for optical devices this level does not change significantly). The above observation is also true when soot or metal powder is used in order to enhance the fingerprint.

• A fingerprint left on a thick (ca 0.5 mm) layer of gel or grease is noticeable but it is very different when observed directly.

• Fingers with a damaged surface still give a relatively clear image. Their internal structure seems to be visible, since the phenomenon on which our observations are based applies to the near surface layer.

7. Future work

In the near future, we plan to develop a new model of the camera that will be based on fixed transducers and will be capable of showing "live" pictures of objects at 25 frames per second. It will be a kind of a "real-time" ultrasonic camera which can see the near surface structures of objects placed on its sensitive surface. The camera will contain its own electronic circuit for reconstruction and will have an output for a standard monitor. The camera used at present is based on a moving transducer and can produce a few frames per second. It also needs a computer which performs the signal processing and displays the image. In 1998, we plan to develop an integrated version of the device. Eventually, we hope to implement it in a kind of chip.

References

[1] E. Newham, *The Biometrics Report*, SJB Services.

[2] D. Mohrmann, *Biometrie als Quantensprung?*, W&S, 7, p. 28 (1997).

[3] H. Mueller, *Der Koerper als Passwort*, PC Magazin, p. 256, Januar 1998.

[4] F. Galton, *Finger prints*, published in 1892 by Macmillan and Co., London and New York, reprint: Da Capo Press, New York 1965.

[5] H.C. Lee, R.E. Gaensslen, *Advances in Fingerprint Technology*, Elsevier, 1991.

[6] L.H. Andersen, Peter Juergensen, *Fingerprint verification – for use in identity verification systems*, Master Degree Work, Aalborg University 1993.

[7] Siemens AG, EP 0 041 693 A1, 1981.

[8] *Fingerprint-Chips*, Markt&Technik, 50, p. 46 (1997).

[9] *Der Fingertip-Sensor*, Blick durch die Wirtschaft, (18/12/97, p. 6), FAZ Verlag, Frankfurt am Main.

[10] Z. Gumienny, M. Pluta, W. Bicz, D. Kosz, *Rekonstrukcja struktur dwuwymiarowych z zastosowaniem algorytmu FFT*, Akustyka Molekularna i Kwantowa, **15** (1994).

[11] Z. Gumienny, M. Pluta, W. Bicz, D. Kosz, *Synthetic aperture acoustic microscope for evaluation of fingertip peripheral skin structure*, SPIE, 2390.

[12] W. Bicz, Z. Gumienny, M. Pluta, *Ultrasonic sensor for fingerprint recognition*, SPIE, 2634.

[13] Z. Gumienny, M. Pluta, W. Bicz, D. Kosz, *Ultrasonic setup for fingerprint patterns detection and evaluation*, Acoustical Imaging, **22** (1996).

[14] Sonident, World Patent WO-A-8 705 790.

[15] Sonident, US Patent Nr. 5258922.

[16] Sonident, US Patent Nr. 5515298.

[17] B. FAY, *Strukturuntersuchungen mit Hilfe der Ultraschallrueckstreuung*, in K. Brendel (Ed.) Stand und Entwicklungstendenzen der Ultraschallmesstechnik (Vortraege des 64. PTB-Seminars am 23./24.04.1986).

[18] G.T. HERMAN, A.K. LOUIS, F. NATERRER [Eds.], *Mathematical methods in tomography*, Proceedings, Springer Verlag, Oberwolfach 1990.

[19] A.C. KAK, M. SLANEY, *Principles of computerized tomographic imaging*, IEEE Press, 1988.