

ULTRASONIC SENSOR FOR FINGERPRINTS RECOGNITION

Wiesław Bicz

Research-Production Enterprise OPTEL Ltd.
ul. Otwartą 10a, 50-212 Wrocław, Poland

Zbigniew Gumienny, Mieczysław Pluta

Institute of Physics, Technical University of Wrocław
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

ABSTRACT

The paper presents prototypes of ultrasonic sensors for fingerprint pattern recognition. Their principle of operation is based on the amplitude measurements taken in selected points of acoustic field of ultrasonic wave diffracted from subsurface finger structure. Examples of sensor construction and measured data are presented. Fingerprint structure recognition from pulse echo shows the possible use of the sensor as a synthetic aperture microscope.

1. INTRODUCTION

Wherever it is necessary to check if a person is authorized to use a service, open a compartment or a car, start a machine or device, to get access to confidential data bank, there is obvious the need for a system enabling identification of the person. How indispensable are these systems is evidenced in the fact that only in 1993 banks lost more than three billions dollars due to credit cards forgery¹.

It is widely known that fingerprints of different people are different and from some age on remain unchanged². Therefore, due to achievements of dactyloscopy, criminologists are able to uniquely ascertain a culprit basing on fingerprints left on the place of crime. So far, optical sensors for recognition of fingers³ and palm of the hand (as well as the eyeground)⁴ have been exploited in practice. However, they have not been used widely. Their basic drawbacks are: high cost of production and operation, great amount of data to analyse and store, as well as high degree of deceptiveness (they can react to a dummy), and, in case of a finger or the palm of a hand, this method is not dirtproof⁵.

Diffraction picture of a finger surface, due to locally periodic structure of fingerprint lines, is simpler to analyse than that obtained in direct representation. An analysis of optical diffraction picture of a finger surface is practically impossible because of insignificant diffraction angle of a light wave since its wavelength is very small if compared to the distance between particular fingerprint ridges. On the other hand, acoustic waves of ultrasonic range propagating in a solid or liquid may have length comparable with dimensions of the fingerprint lines structure. The angle of diffraction of this wave may be greater and distribution analysis of the diffraction acoustic field becomes possible. Acoustic waves are subjected to diffraction not only on the subsurface finger structure but also on deeper skin layers⁶. It may be expected that due to uniqueness of skin structure and its specific physical features^{7,8} preparation of an artificial finger would be very complicated and expensive.

It appears that replacing light waves by acoustic waves and analyzing the diffraction picture instead of the direct one seems to be reasonable on the ground of presented above reasons.

2. THEORETICAL BASIS

The description of phenomena associated with diffraction of ultrasonic waves is analogous to that applied to the theory of optical holography. The description to follow is simplified but sufficient to understand how an acoustic sensor for fingerprint recognition works.

A planar acoustic wave propagating in a homogeneous, elastic medium is described by the function:

$$\Psi(x, y, z, t) = ae^{i(\omega t - \vec{k} \cdot \vec{r})} \quad (1)$$

where Ψ means the disturbance of the medium in the point $\vec{r} = [x, y, z]$ in the moment t , ω is the (circular) frequency, $\vec{k}$ is the wave vector of a wave with length λ and amplitude a :

$$\vec{k} = [k_x, k_y, k_z]; \quad |\vec{k}| = \frac{2\pi}{\lambda} \quad (2)$$

The vector $\vec{k}$ is perpendicular to the front of wave (1). This wave splits into a series of plane waves when it falls on a two-dimensional diffraction grating placed in the plane xy described by:

$$\tau(x, y) = A \cos(\vec{K} \cdot \vec{r}) = A \cos(K_x x + K_y y) \quad (3)$$

$\vec{k}$ is the wave vector of the diffraction grating of the constant Λ and amplitude A :

$$\vec{K} = [K_x, K_y]; \quad |\vec{K}| = \frac{2\pi}{\Lambda} \quad (4)$$

The coordinates of the wave vectors of splitted series plane waves are as follows:

$$\begin{aligned} k'_x &= k_x + nK_x \\ k'_y &= k_y + nK_y \\ k'_z &= m\sqrt{k^2 - k_x^2 - k_y^2} \end{aligned} \quad \begin{aligned} n &= \pm 1 \text{ (order of diffraction)} \\ m &= \pm 1 \text{ ("-" for reflected wave)} \end{aligned} \quad (5)$$

The amplitudes of diffracted waves are proportional to grating amplitude. In a case of objects more complicated than described by $f(x, y)$ (e.g. fingerprint lines) it is possible to treat them as a superposition of many diffraction gratings with different vectors K . The amplitude $A(K_x, K_y)$ of each component can be obtained using two-dimensional Fourier transform:

$$A(K_x, K_y) = F[f(x, y)] = \frac{1}{4\pi^2} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} f(x, y) e^{-i(K_x x + K_y y)} dx dy \quad (6)$$

From equations (5) and (6) we see that the amplitude distribution of diffraction field for an object $f(x, y)$ is described by its Fourier transform. The correspondence between the object and its Fourier transform is one to one (Fig. 1). Hence, it may be concluded that the distribution of diffracted acoustic field represent unequivocally the pattern of finger surface on which the diffraction occurred.

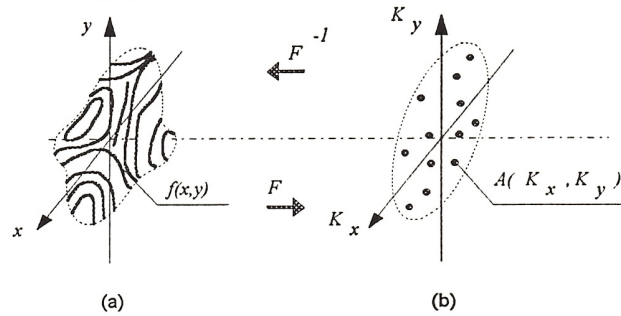


Fig.1. Correspondence between the object (a) and its Fourier transform (b).

3. ULTRASONIC DETECTION METHODS OF FINGERPRINT DIFFRACTION SPECTRUM

The finger surface with a pattern of fingerprint lines may be treated as a complicated reflecting diffraction grating. Complexity of this grating results from:

- curvature of fingerprint lines
- variation of direction and density of these lines
- natural ability of elastic structure distortion
- multilayer structure (besides the echo from surface a reflection from deeper layers is observed)

In all of the experimental systems built by the authors till now, the finger tip was applied to a solid window (plexiglass, glass) mounted on a vessel filled with water, in which sending and receiving ultrasonic transducer are placed.

3.1. Relationships between basic physical parameters

The distance between fingerprint lines vary within the range 0.25 - 0.75 mm. For further considerations we will take an average value of $d = 0.5$ mm, hence $|K| = 2\pi/0.5 \approx 12.5 \text{ mm}^{-1}$. A wave with length λ falling on the diffraction gratfor ing deflects with the angle described by equation (5). Considering diffraction in the plane perpendicular to the fingerprint lines (Fig. 2) we obtain:

– for transmitter located on axis ($k_x = 0$) (Fig. 2a)

$$k'_x = K_x, \quad \sin \alpha = k'_x / |k| = \lambda / d$$

– for sending-receiving transducer located at one side (Fig. 2b) $kx' = -kx$; substituting into (5) we get

$$-k_x = k_x + K_x, \quad \sin \beta = k'_x / |k| = \lambda / 2d$$

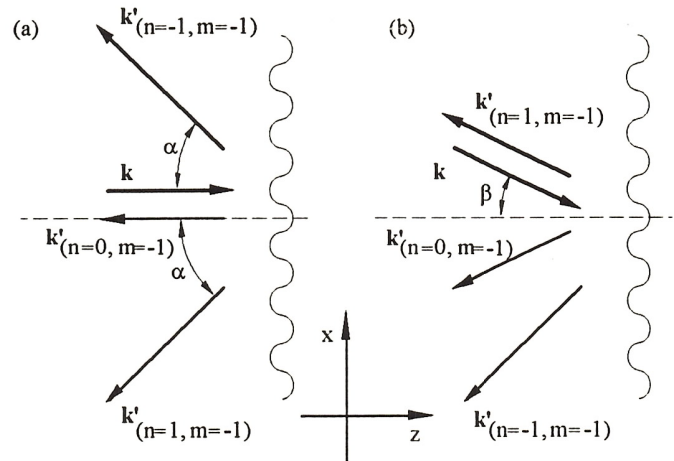


Fig. 2. Schematic picture of diffraction in two interesting cases.

Further in this paper, the systems with the central sending transducer will be referred to as the systems of type A, while the systems with movable sending-receiving transducer will be referred to as type B. The detection of diffraction maxima for various grating constants d is obtained by changing of the location of receiver or changing the ultrasonic waves frequency. For type A systems the following values are accepted: average angle of receiver inclination $\alpha \approx 30^\circ$, $\lambda = 0.25$ mm what corresponds to the frequency $\nu = 6$ MHz. For type B systems $\beta \approx 15^\circ$, $\lambda = 0.25$ mm, and $\nu = 6$ MHz.

3.2. System for scanning over sphere (type B)

Figure 4 shows a scheme of the system for scanning over sphere. It is a successor of a system scanning over plane, created earlier. A small plexiglass window O, to which finger is applied, is located at the origin of coordinate system XY . Sending-receiving piezoelectric transducer moves over sphere with radius R , which centre of curvature agree with the coordinate system origin. The transducer has two degrees of freedom. It may be deflected angularly relative to the axes ω_1, ω_2 , which coincide with the axes x, y , respectively. The angular range of transducer deflections is $\pm 45^\circ$, and the angular resolving power is 0.036° . The whole distribution of acoustic field is measured at one frequency ν . Correct diffraction pictures of fingerprint structure were obtained for planar transducers with large diameter and plane finger window, as well as for point transducers and spherical finger window (with radius of curvature $R' = -R$). In the last case the finger was applied to the convex surface of window. In spite of obtained good quality of diffraction picture it is hard to expect that this system would find wide application because of long time of acoustic field scanning and complicated mechanics. Additionally, this system is sensitive to the orientation of fingertip application since the system does not assure rotational symmetry. Fig. 4(a) and 5(b) show examples of diffraction field distribution measured by this system.

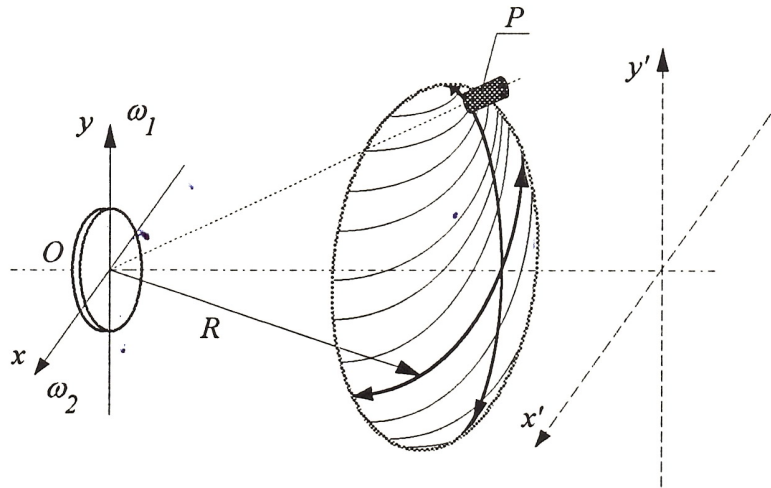


Fig. 3. System for scanning over sphere.

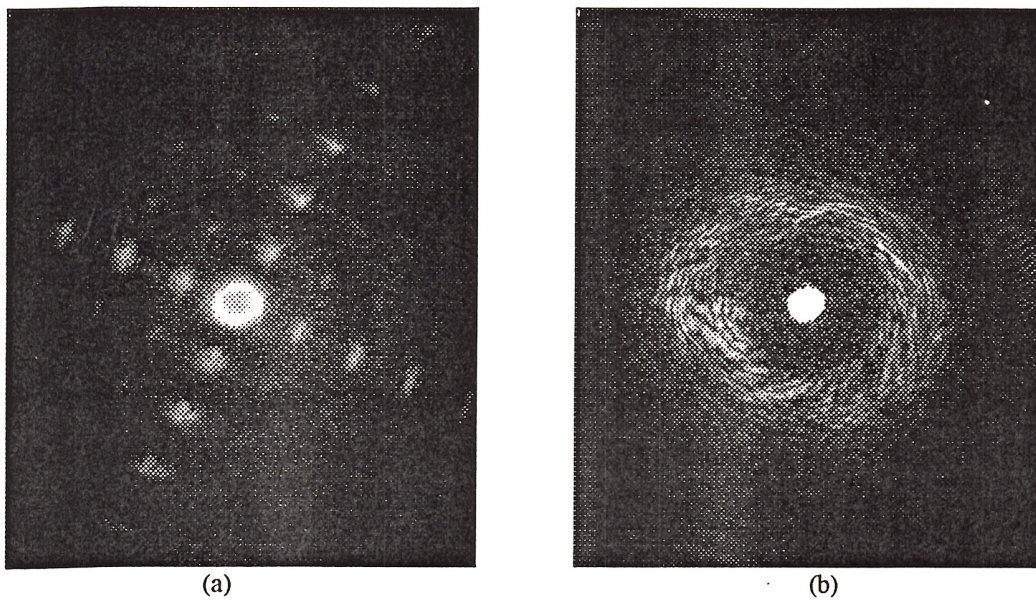


Fig. 4. Measured diffraction patterns of: (a) grid with line distans of 1mm, (b) fingerprint.

3.3. Scanning over circle system (type B)

From the analysis of diffraction pictures of different fingerprints taken with the previous (Fig.4b) system it appears that most information about the subsurface finger structure is comprised in relatively small area of ring shape with width Δr , surrounding a circle with radius r (Fig. 5a). Since the diameter of this circle depends on the geometry of measurement system and on frequency ν , an aperture coefficient g was introduced, normalizing this dimensions to the size of diffraction picture in space of vector $\mathbf{K}$.

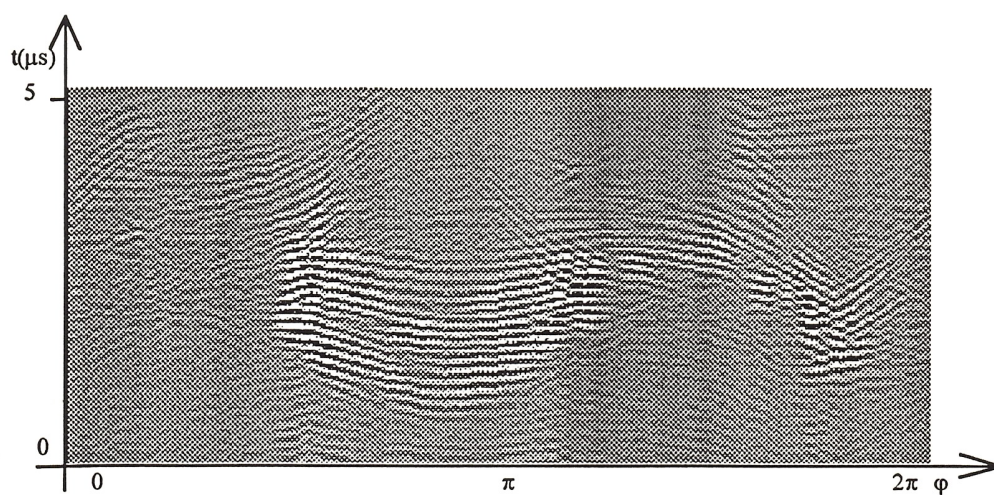


Fig. 7. Matrix of pulse responses of a fingerprint.

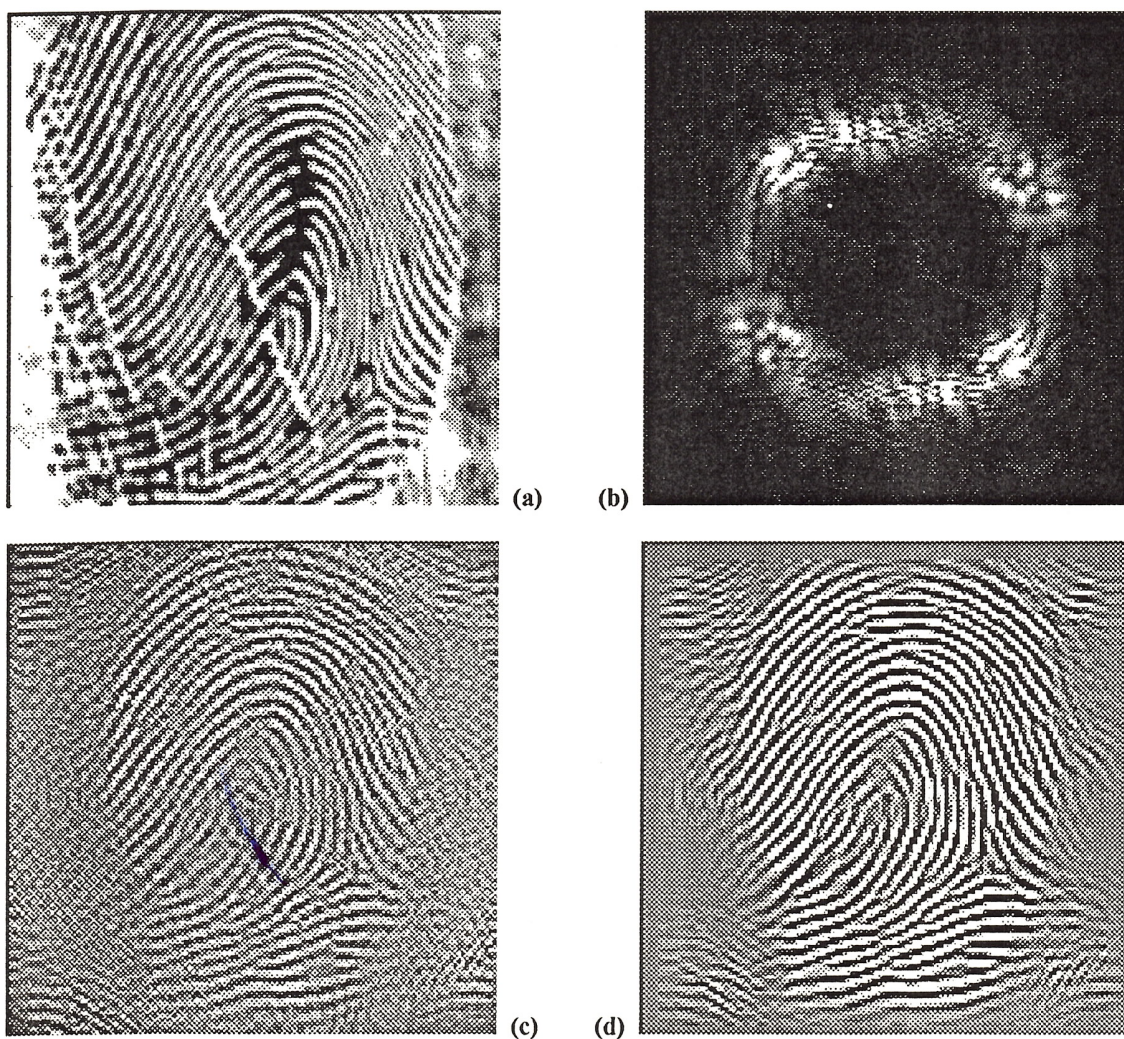


Fig. 8. Some representations of a fingerprint structure, a) optical picture, b) Fourier transform, c) reconstruction from acoustic pulse response matrix (Fig. 7); d) the same as (c) but after image processing.

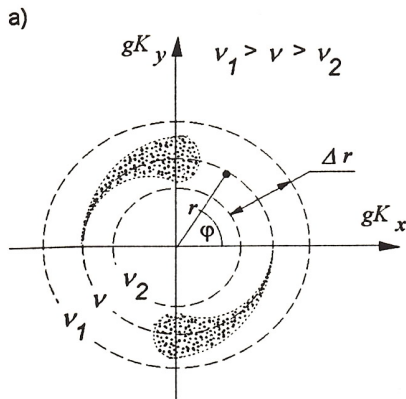


Fig. 5a. Comments in text.

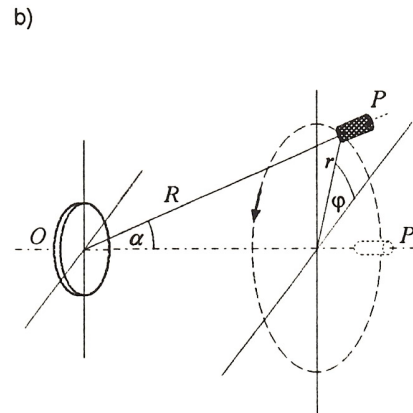


Fig. 5b. Scanning over circle system.

In the system shown in Fig. 5b, the acoustic field scanning is performed for 2048 points laying on the circle with radius $r = \text{const}$. The positions of measurement points are specified by rotary-impulse transducer coupled with the movement of sending-receiving transducer P . The transducer axis is directed towards the middle of the window O with angle α from the main axis of symmetry. In this system, the radial scanning effect is obtained by changing wave frequency (g is changed). Assuming that scanning of field over circle with radius r is performed with frequency ν , and after frequency change to $\nu_1 > \nu$ the diffraction angle will decrease, which realizes the situation that on circle r there would be located external boundary of new ring of the diffraction field (Fig. 5a). (The situation will be opposite when we change frequency to $\nu_2 < \nu$). Also the system have been constructed, in which sending-receiving transducer set was divided into two separate transducers. One of them P' (fixed) was placed centrally at the distance R from the window O (Fig. 5b). In this system version, in purpose of avoiding of the change of angle α , the wave frequency was increased twofold. While not scanning the whole diffraction field, this system does not have drawbacks of the system described in section 3.2. An additional advantage is in simpler measurement control.

3.3.2. Pulse measurements

The scanning-over-circle system enables carrying pulse measurements, that means sending short pulses and recording the reflected signal with an oscilloscope board.

The laboratory system for fingerprint reconstruction comprises three main functional blocks.

Mechanic-acoustic head (Fig. 6) consists of:

- composite 6 MHz transducer
- water-filled vessel with measurement window at bottom
- mechanical system with step motor
- step motor controller
- position sensor

In the sending-receiving block there are:

- pulse generator
- signal switch
- preamplifier

Computer 486/33 Mhz with additional cards:

- 40 MHz scope board
- digital processing (DSP) card

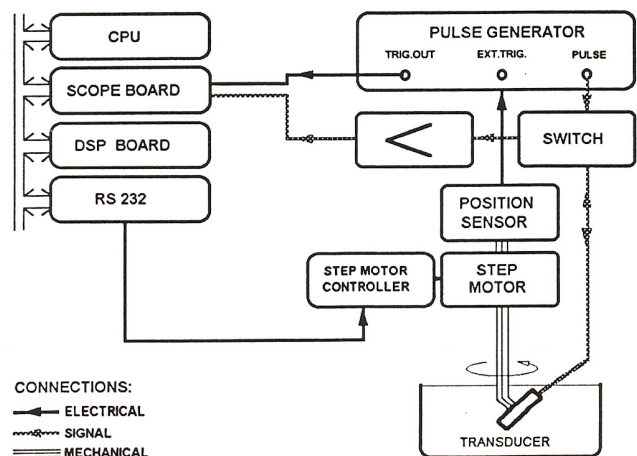


Fig. 6. Block diagram of the measurement setup.

The transducer sends acoustic pulses and receives as the echo a wave diffracted on fingerprint lines for every one position during rotation. These transient responses are sampled by scope board and stored in measurement matrix of 256×256 elements. Basing on such measurements the reconstruction of fingerprint lines becomes possible. The reconstruction procedures⁹ were presented on the conference in Wisla¹⁰. The reconstruction algorithm is accomplished by computer and DSP card, but in fact the DSP card mainly performs FFT or back projection calculations. The measurement cycle with object reconstruction lasts about 8 seconds. We can treat our setup as an acoustic syntetic aperture acoustic microscope.

3.4. Fixed system (type A)

The experience gathered during work with the system described in section 3.3 was exploited in construction of a head with electronical, instead of mechanical, scanning. Scheme of this head is presented in Fig. 9. It contains 256 receiving transducers P , each with area of 1 mm^2 , arranged on the circle with radius $r = 50 \text{ mm}$ and at angle $\alpha = 30^\circ$ to the system axis. The focus of a spherical transmitting transducer P' is positioned at the same distance $R = 100$ as the receivers P . The active diameter of the transmitter is equal 16 mm. The spherical window made of plexiglass has the diameter 50 mm and the radius of curvature $R' = -R$. As in the previous system, the head ensures scanning of diffraction field from a ring area, which contains essential information about subsurface fingerprint structure. The head, along with a multiplexer and a controller, is a part of a measurement system for fingerprint recognition.

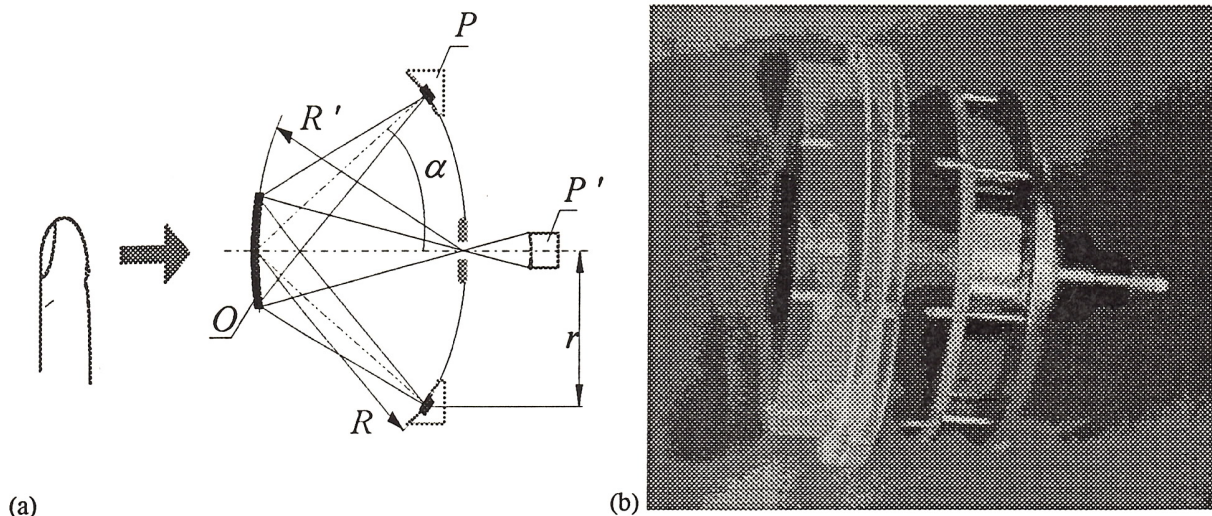


Fig. 9. Ultrasonic head without moving elements: (a) scheme, (b) realization.

The gathered in measurement information about the acoustic field distribution is compared with data stored in a microcomputer memory or saved on a card supplied with magnetic data carrier (e.g. chip card). Comparison is conducted by a microcomputer equipped with specialized software.

4. FINAL REMARKS

The measurements and reconstruction of fingertips pictures showed that diffraction of acoustic field occurs on structures identical with fingerprint lines. Reconstruction of different structures, giving weaker diffraction echo, for example: rubber stamp, diffraction grating, were also obtained. The analysis of reconstruction errors of this structures enabled to determine an apparatus function of the measurement system. Owing to this, considerable analyse quality improvement of reconstruction pictures was achieved. We can treat our pulse system as an synthetic aperture acoustic microscope, the system separates lines 0.3 mm apart with 20 mm field of view. The replacement of moving transducer by ring matrix of point transducers switched by a multiplexer will convert the described system into a fast ultrasonic Fourier microscope. At present, besides the basic research on ultrasonic wave propagation in different media, studies are continued on optimization of mechanical and electronic construction as well as on improving technology of ultrasonic head for mass production. In the nearest future statistical studies are planned. Their purpose is improvement of the procedures for fingerprint diffraction picture recognition.

5. REFERENCES

1. Kriminalität, "Mafia nera", *Der Spiegel*, No.11, p. 81, März 1994.
2. Cz.Grzeszyk, *Daktyloskopia*, PWN, Warszawa, 1994 .
3. A.Beutelspacher, A.Kersten, A.Pfau, *Chipkarten als Sicherheitswerkzeug*, Springer-Vg, Berlin, 1991.
4. J. Beyer, M. Buchner, "Nur das richtige Auge öffnet die Datenbank", *Impulse*, No.3, pp. 174 - 176, März 1994.
5. Sicherheit, "Weiße Elefanten", *Der Spiegel*, No.20, pp. 62 - 63, Mai 1989.
6. P.Altmeyer, S.el-Gammal, K.Hoffman, *Ultrasound in Dermatology*, Springer-Vg, Berlin, 1992.
7. W.Montagna, P.F.Parakkal, *The Structure and Function of Skin*, Academic Press, London, 1994.
8. W.Montagna, A.M.Kligman, K.S.Carlisle, *Atlas of Normal Human Skin*, Springer-Vg, London, 1992.
9. G.T. Herman, "Image Reconstruction from Projections", *Topics in Applied Physics* , vol. 32 , Springer-Vg, Berlin, 1976
10. W.Bicz, Z.Gumienny, D.Kosz, M.Pluta, "Fourier transform pattern reconstruction", *II Bilateral Polish - German Symposium on Ultrasonic Measurements Methods in Science and Technics*, Wisła, Poland, Febr. 1994.