# Model of 2D Optical Correlator for Fingerprint Identification

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## SUMMARY

This paper is devoted to the fingerprint identification problems and the experimental models of relevant optical setups. As published last year, some possibility of a fingerprint identification by means of 1D cut correlation has appeared. The first section of this paper deals with an improvement of our previous method based upon a 1D cut correlation. Originally a fingerprint photographic film record was used. Recently a fingerprint is displayed on a 2D hi-res LCD panel SHARP.

The second section of this paper is oriented to a comparative experimental verification of widely used JTC as a reference 2D correlation method.

Finally, a set of experimental data for both techniques is presented.

## PREVIOUS RESULTS

As we published in our paper at the 1995 Carnahan Conference, our identification model was based on the evaluation of the correlation of particular linear fingerprint cuts. In the first step, we applied a linear cut of fingerprint and a linear 1D LCD array to create an analyzed picture. In both cases, an acousto-optic 1D SLM (spatial light modulator) formed a reference image. During the initial period, the optical setup with a fingerprint photographic record was also tested for identification. See Figure 1 on next page.

This simple correlator setup was chosen to comply with our idea to construct a massively parallel but low-cost optical system. The technical aim was to verify techniques suitable for very fast performance (real- or near-real-time) for an identification in a limited size database, e.g., authorized personnel (several hundred individuals). The fingerprint was chosen because of the anticipated simplicity of the sensing device; but, in the future, it will be possible to introduce other anthropometric or technical evaluations, such as spectroscopic patterns, DNA fingerprints and chromatograms.

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Based on a presentation at the 1996 Carnahan Conference.

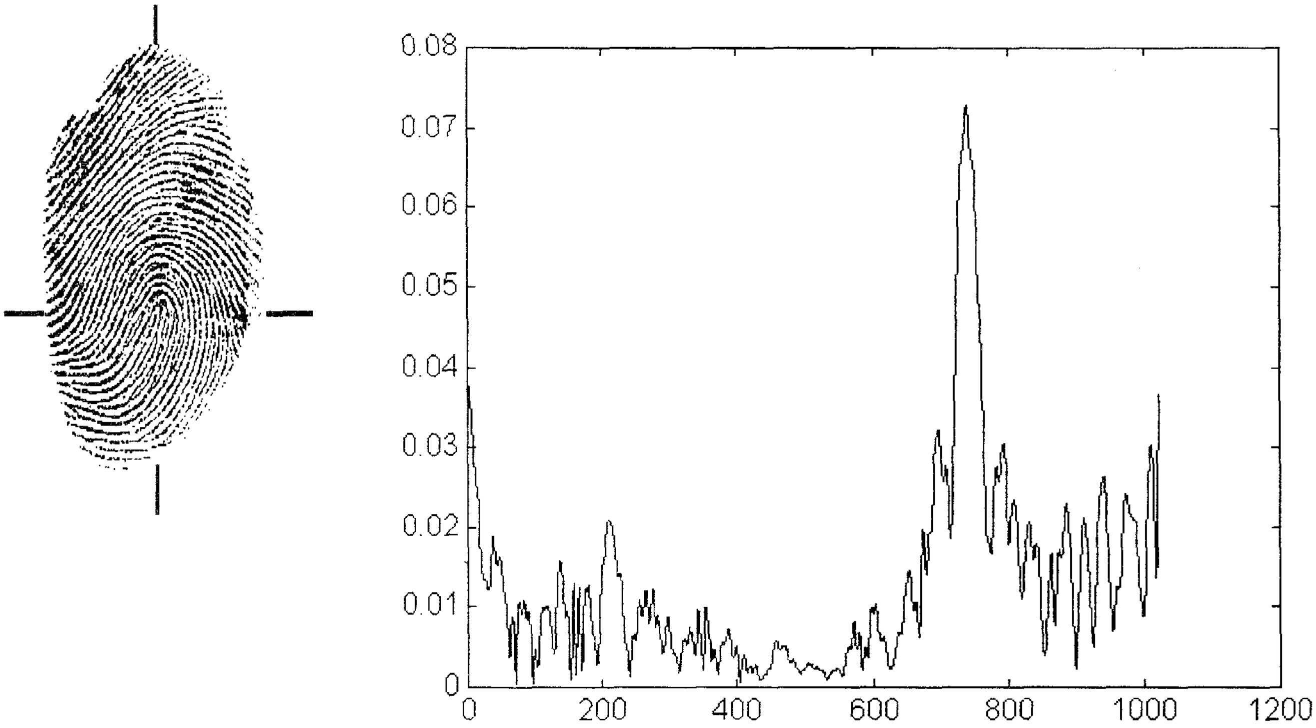

**Fig. 1. Correlator with Slide Reference**

## 1D CORRELATOR WITH HI-RES 2D LCD REFERENCE — EXPERIMENTAL RESULTS

Based on the results mentioned above, we designed and assembled the second generation of an optical correlation setup. The crucial part of our optical system was a hi-res active LCD panel from the Sharp Company, originally used in TV projectors. Parameters of the LCD panel are shown in the Table 1.

**Table 1. Technical Parameters of LCD Panel**

| | |
|---|---|
| Dimensions: | 7.6 cm diagonal (3″) |
| Contrast Ratio: | 100:1 |
| Refreshing Rate: | 50 Hz |

The overall optical setup of our experimental model was slightly modified as sketched in Figure 2, next page. The beam from an argon laser ILA 120 (wavelength 541 nm; manufacturer Karl Zeiss Jena) is expanded by a beam expander 1:20. The output beam is vertically polarized and the residual parasitic light from the discharge tube is suppressed by an interference filter. Then, the laser beam passes through the LCD panel. To avoid difficulties with reflected beams, the LCD panel is tilted slightly from the vertical direction. The 2D fingerprint picture is supplied to the LCD panel from a computer and a particular horizontal cut is separated by a single slit. A fingerprint is shown in inverse mode (white lines on black background) in order to reduce a scattered light level as much as possible. Real complex grid structure of the TFT LCD panel introduces a significant amount of diffracted beams. The switching rate of the TFT LCD panel limits the overall computational power. Our LCD panel has been designed for standard TV operation — one frame per 40 msecs; one field per 20 ms. Because the panel resolution is roughly 300 pixels only, both fields are identical and we can use them as a noninterlaced raster scan with half of the resolution.

After the slit, the fingerprint cut image passes through the acoustooptic SLM. We have applied a high resolution SLM acoustooptic unit made by the Isle Optics Company, UK. The unit is based upon a single crystal of mercurous chloride and exhibits the following parameters:

| | |
|---|---|
| Acoustic Wavevelocity | 347 m/sec |
| Optical Aperture | approx. 30 mm |
| Acoustic Aperture | 85 μsec |
| Theoretical Resolution | 2550 pixels |
| Acoustic Central Frequency | 60 MHz |
| Acoustic Bandwidth | 30 MHz |
| Driving Power | 600 mW |

The cylindrical telescope is applied for better geometrical matching of beam vertical dimension and the optical aperture of the acousto-optic unit. Theoretically, the resolution limiting element is the LCD panel. According to our experiments one can say that the real resolution of 100 pixels is sufficient for this particular fingerprint comparison. The acousto-optic unit is supplied by an AM signal and the modulation relief is given by a particular fingerprint cut. We can provide the new sample

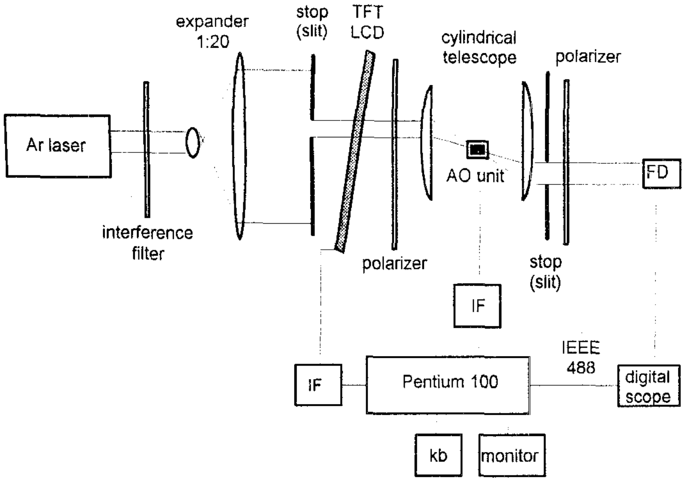

**Fig. 2. Correlator with LCD 2D Panel**

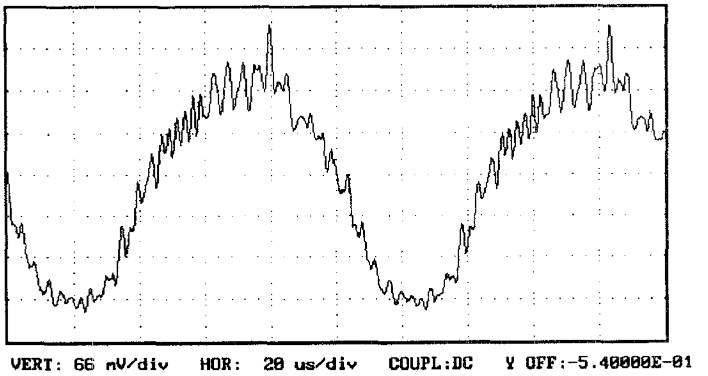

**Fig. 3A. Correlation of Fingerprint Cut — Uncompensated**

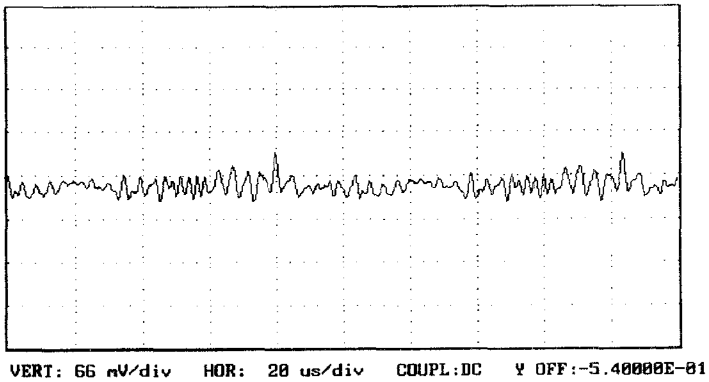

**Fig. 3B. Correlation of Fingerprint Cut — Compensated**

**Fig. 3. Correlation of Fingerprint Cut**

every 100 µsec — it means that we can compare 10,000 fingerprint cuts from a database per second. For the resolution limit of 100 pixels per cut, we can estimate a required signal dataflow around several Mbits per second. To avoid significant intermodulation effects due to nonlinear transfer function, the operational value of diffraction efficiency was reduced to approximately 1%, and, in consequence, a powerful argon laser was used.

After leaving the acousto-optic unit, the beam energy is integrated, and finally detected by, a photomultiplier.

Experimental results of optical correlation calculation are shown in Figure 3. Figure 3A displays an optical detector output when identical cuts are compared. The multiplying effect of a Gaussian laser beam profile is apparent. Figure 3B shows the same correlation signal when the Gaussian beam profile is compensated.

## PSEUDO 2D CORRELATOR WITH LCD REFERENCE (MULTICHANNEL 1D VERSION)

A similar optical setup as shown in Figure 2 can be applied as a pseudo 2D correlator if the multiline version is used. Both slits are removed and instead of the integral photodetector, the 1D linear detector array is placed. In this case, we can express correlation function for all LCD image lines in parallel with the same common reference in the acoustooptic unit. This configuration will improve overall performance significantly.

Another modification is an application of multichannel acousto-optic SLM in order to provide several sets of data from a database. This configuration will compare one line on the LCD panel with several references in parallel.

## JOINT TRANSFORM CORRELATOR (JTC)

The most interesting technique for optical fingerprint identification was introduced in the early 80s and is continuing to develop. We have tested a simple configuration to gain knowledge related to this truly 2D correlation technique.

The optical principle setup is sketched in Figure 4. Basically, it forms an optical Fourier transform system. Two compared images r(x,y) and s(x,y) are displayed on the same SLM side-by-side shifted a and -a respectively, from the central position [2] and the forward Fourier transform is performed by the first transforming lens. Then in the spectral plane, the created spatial spectrum must be modified by quadratic function. It can be done by various methods, e.g., photographic record, photorefractive material, etc. In our case, we simulated this quadratic function in a computer in this phase of experiment.

$$I(u,v) = \left|FT\left[\left(r(x-a,y)+s(x+a,y)\right)\right]\right|^2 =$$

$$= \left|R(u,v)+S(u,v)\right|^2 = R(u,v)R^*(u,v)+S(u,v)S^*(u,v)+$$

$$+R(u,v)S^*(u,v)\exp(i2\pi ua)+S(u,v)R^*(u,v)\exp(-i2\pi ua)$$

where I(u,v) = intensity distribution in the Fourier plane.

The square of original FT is inversely transformed by the second transforming lens. According to the convolution (correlation) theorem, after the inverse

Fourier transform, we locate in the output plane, several maximums of intensity. They are located at the point

at the point 0 $\quad r(x,y) \otimes r(x,y) + s(x,y) \otimes s(x,y)$

at the point +2a $\quad s(x,y) \otimes r(x,y)$

at the point -2a $\quad r(x,y) \otimes s(x,y)$

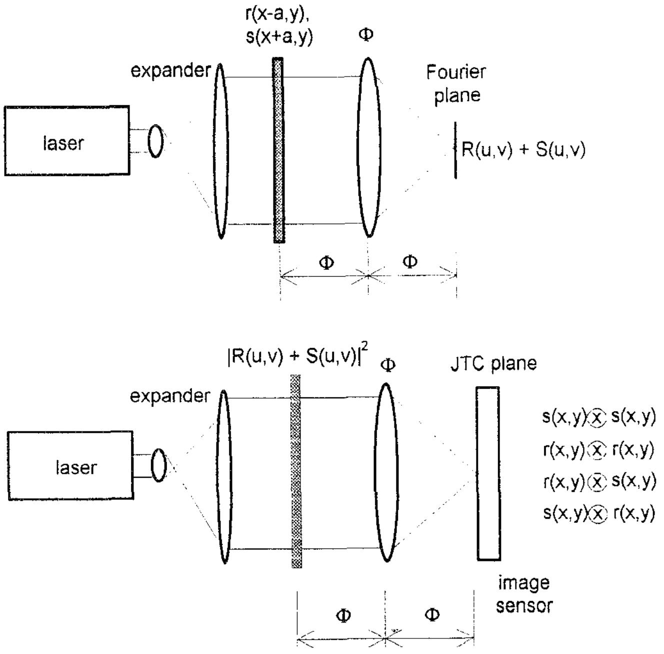

**Fig. 4. JTC Optical Setup — Principle**

The first term is the autocorrelation functions, but the second and the third terms give us the required crosscorrelation value.

## EXPERIMENTAL JTC VERIFICATION

Experimental verification of the JTC technique has been done with the modified optical setup as shown in Figure 5. The LCD SLM used was the Sharp XV 330 H mentioned above. Because the required optical power is reduced significantly, we used the YAG solid-state laser with optical frequency doubling model No.LL-01cc, manufacturer: Laser-Compact Co., Ltd, with an output power 0.3 mW. A positive lens with a focal distance of 300 mm, dia 60 mm, has been used as a transforming lens. The output image sensor was a TV rate CCD camera MTV — 231CM, 1/3″ dia, delivered by MIT.

The detailed configuration of our test images is shown in Figure 6. On the left side of the image, three objects are placed — two patterns of the same fingerprint (to get a normalising constant) and one pattern of a modified test fingerprint. On the right side of Figure 6, the final JTC output picture is demonstrated. The test fingerprint in Figure 6 is the same fingerprint rotated 5° counter-clockwise.

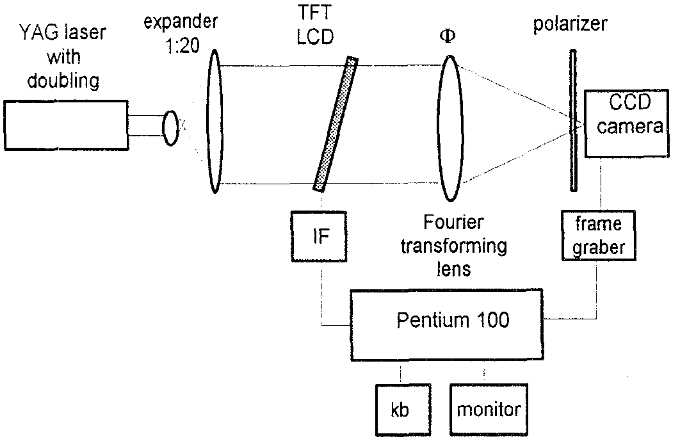

**Fig. 5. JTC Optical Setup**

**Fig. 6A.**

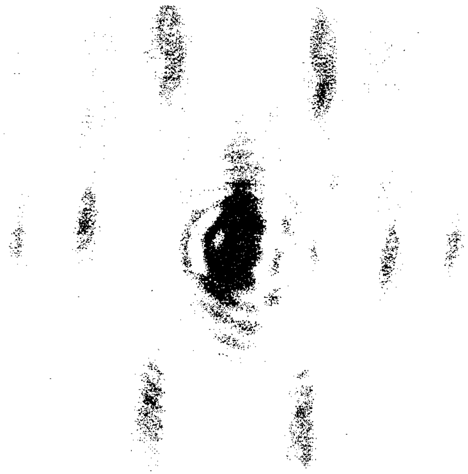

**Fig. 6B.**

**Fig. 6. Detailed Configuration of Test Images**

Figures 7 - 9, shown on the next two pages, are based on similar configuration of input patterns but with different test fingerprints:

All 2D JTC patterns are accompanied by the intensity profile cuts through identical and test correlation maximums.

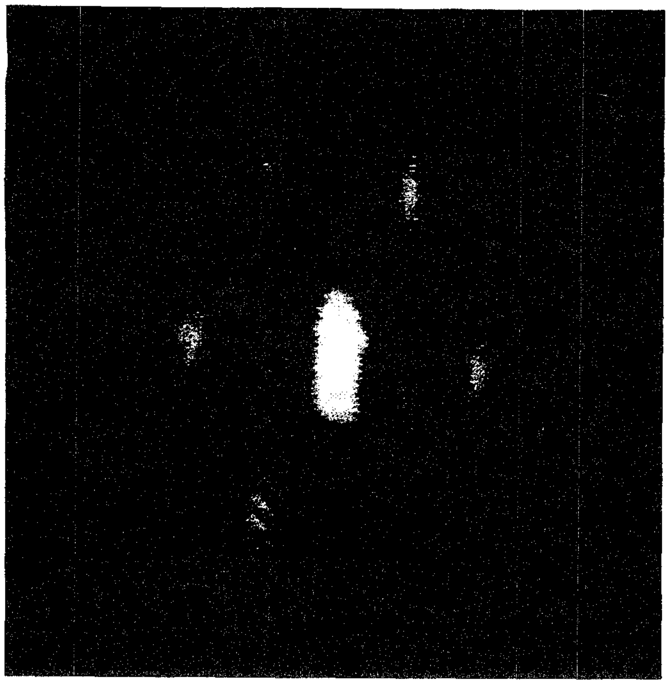

**Fig. 7A.**

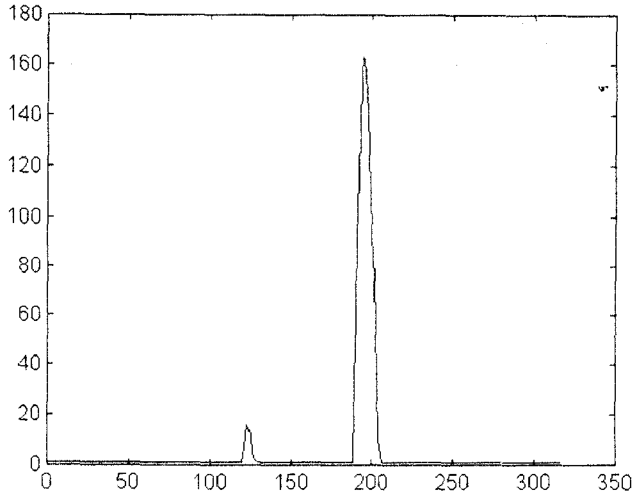

**Fig. 7. Test Fingerprint of Different Persons**

## COMPARISON OF APPROACHES

It is apparent that both approaches can hardly be compared. The JTC method is fully two-dimensional and relatively insensitive to rotation in a scale of several degrees. The optical system requires a very high optical quality of elements to achieve a reasonable signal-to-noise ratio.

The cut correlation method is relatively simple but sensitive to any geometrical deformation and/or transformation and both test image and reference image have to be positioned precisely.

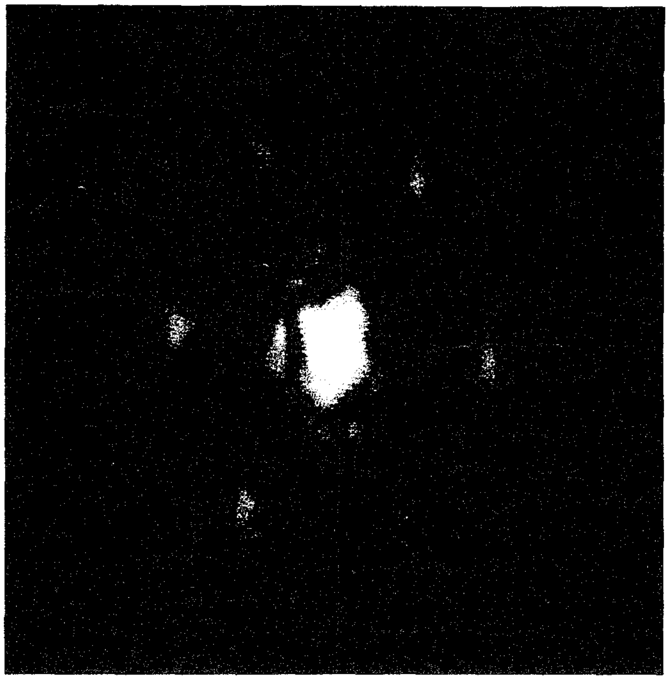

**Fig. 8A.**

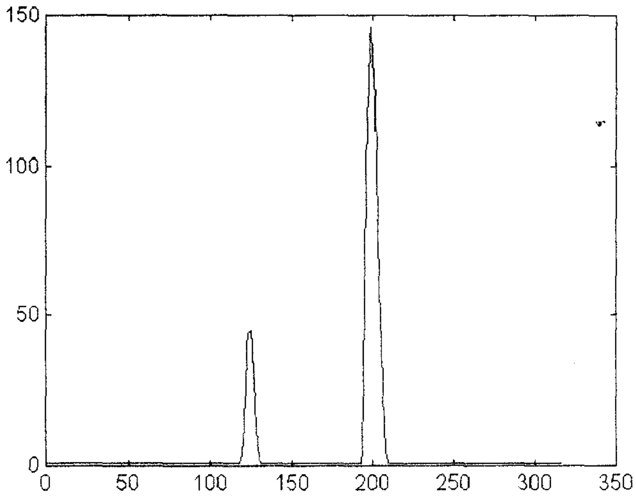

**Fig. 8B.**

**Fig. 8. Test Fingerprint of the Same Person Rotated 20° Counter-clockwise**

## CONCLUSION

The field of optical information processing is expanding dramatically. Inherent massive parallelism, 3D interconnections and very high speeds of computational performance exceed, in many cases, performance capabilities of electronic systems. Some operations, such as analog multiplication, convolution, correlation and Fourier transform, are based on natural properties and principles of optical processing systems. The wide selection of applications is described in [3, 4].

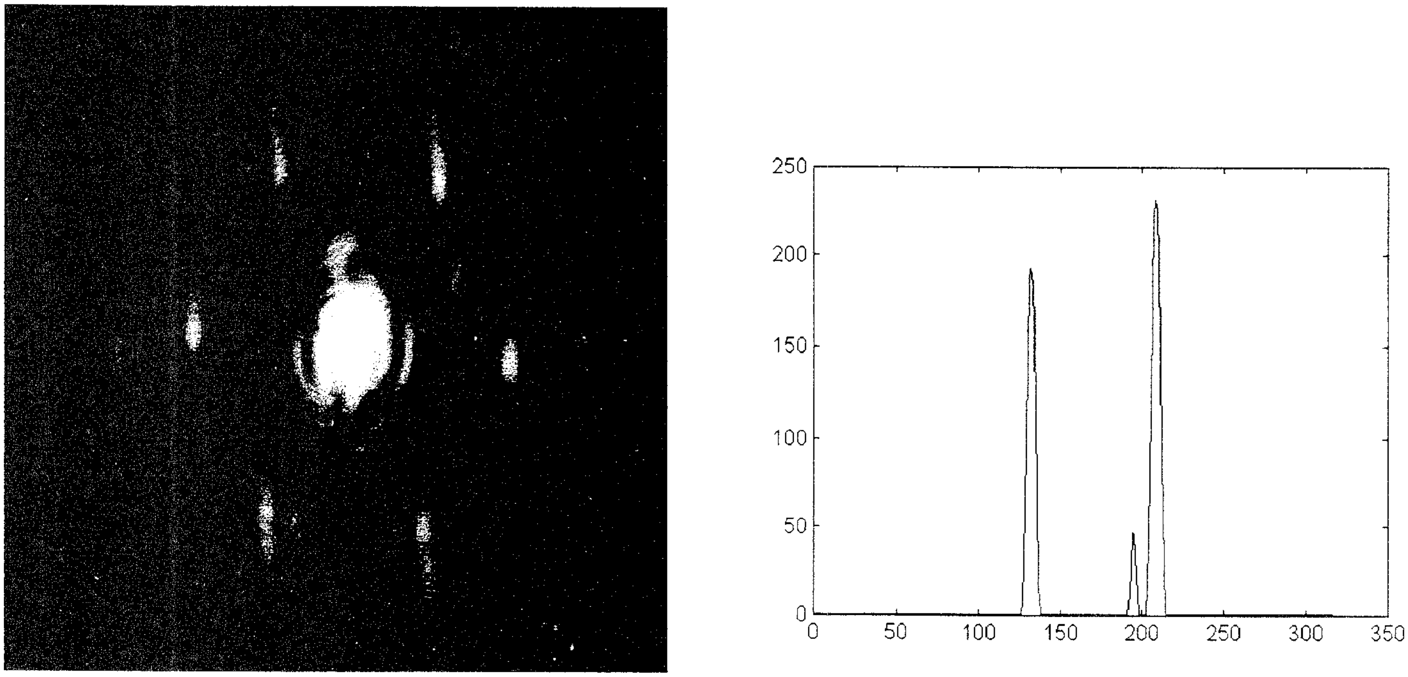

Fig. 9A.

Fig. 9B.

**Fig. 9. Test Fingerprint of the Same Person Rotated 1° Anticlockwise**

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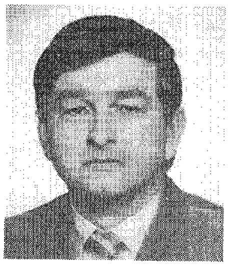

**Miloš Klima** received his M.Sc. from the Czech Technical University in Prague, 1994, and his PhD at the same university in 1978. Recently, he was an Associate Professor and a Deputy Head of the Department of Radioelectronics, Faculty of Electrical Engineering of the Czech Technical University. During the last twenty years, he has been involved in R&D activity in the field of acoustooptic elements for laser beam control, imaging TV systems under the space program *Interkosmos* (X-ray image sensors for the study of solar activity) and, more recently, optical methods for information processing. His educational activities are related to Photonics and Image Processing.

**Jiři Rott** received his M.Sc. in Electrical Engineering from the Czech Technical University, Prague, Faculty of Electrical Engineering in 1994. His thesis was on stereoscopic TV display. Rott is working toward his PhD at the Czech Technical University, Prague, Faculty of Electrical Engineering in the area of optical information processing systems. His research interests are: acousto-optics, photonics, optical correlators, optical matrix - vector multiplication.

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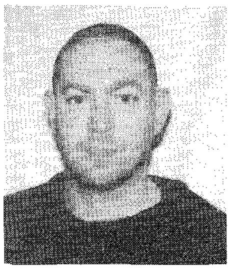
**Daniel J. Gleeson** received his Honours Degree in Physics from Imperial College in London, UK, and his Masters Degree in Astronautics from the University of Hertfordshire, UK in 1986 and 1990, repectively. He joined British Aerospace Space Systems in 1986 where he worked on the design of spacecraft electrical power systems. He was eventually seconded to the Future Space Infrastructure group within BAe, and then inducted into the BAe Management Development Programme. During this time, he spent a year on secondment to McDonnel Douglas Space Systems in California, USA, providing consultancy in spacecraft power systems design. In 1992, he joined Space Technology Ireland Ltd. in a business development role and was appointed to the Board of Directors in 1994 with responsibility for Marketing, Contracts and Operations. Recently, he has been active in the development of commercial optical signal processing applications (through international collaboration) based upon novel acousto-optic spatial light modulators.

**Susan McKenna-Lawlor** is a graduate of the National University of Ireland. Her Ph.D. was awarded for research work carried out at the University of Michigan, USA, on the physics of solar flares. She is currently a Professor of Experimental Physics at St. Patrick's College, Maynooth, Ireland, as well as the owner and Managing Director of Space Technology Ireland, Ltd. (STIL), which produces hardware and software for space applications. STIL is currently building an Energetic Particle Monitor for NASA's Gravity Probe B (Relativity) Mission. It also provides consultancy with respect to problem solving and product development for a wide variety of ground-based industries and is a global distributor of Calomel, a material with properties which render it especially suitable for applications in optical signal processing. McKenna-Lawlor participated in the Solar Flares project of NASA's SKYLAB Mission and was also a Guest Investigator on the Solar Maximum Mission. As Principal Investigator she proposed the first Irish experiment to fly on an ESA spacecraft (the highly successful EPONA instrument on the Giotto mission to Halley's comet). EPONA also secured historic data during the first Flyby of Earth performed by a spacecraft coming from deep space and made important measurements at Comet Grigg-Skjellerup. McKenna-Lawlor also proposed the first Irish experiment to fly on a Russian spacecraft (the SLED instrument on the Phobos Mission to Mars and its Moons) which made pioneering measurements of energetic particles in the close Martian environment. She is currently Principal Investigator for SLED-II on the Russian Mars-96 Mission, as well as Co-Investigator for the MARIPROBE, FONEMA and MAREMF experiments on this spacecraft. She is Team Leader for the Irish experiment LION on ESA's SOHO Mission; Co-Investigator for the RAPID experiment on ESA's Cluster Mission and Co-Investigator for WAVES on NASA's WIND Mission. She was conferred with an Irish Person of the Year award for scientific achievement (1986); awarded the Russian Tsiokovsky Gold Medal for contributions to cosmonautics (1988); made an honorary citizen (for technological achievement) of San Jose, Silicon Valley, USA (1991); presented by ESA with a college commemoration successful involvement in the Giotto Extended Mission (1992); elected a corresponding member of the International Academy of Astronautics (1993); conferred with the Irish Laureate Woman of Europe award (1994).



**John G. Keating** received the B.Sc and Ph.D. degrees from St. Patrick's College, Maynooth, Ireland in 1986 and 1990, respectively. He joined the Department of Computer Science at St. Patrick's College in 1990 where he is currently a lecturer. His research interests are in the areas of Computer Modeling, Signal Processing and Artificial Neural Networks. He is currently involved in a number of projects in the area of Optical Computing and Artificial Neural Networks.