INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4.SMR/845-17

Second Winter College on Optics

20 February - 10 March 1995

Correlation Methods in Optical Information Processing

K. Chalasinska-Macukow

Institute of Geophysics
Warsaw University
Warsaw, Poland

CORRELATION METHODS
IN
OPTICAL INFORMATION PROCESSING

K.Chałasińska-Macukow
Institute of Geophysics
Warsaw University
POLAND

Second Winter College on Optics
TRIESTE - 1995

Warsaw
University

OUTLINE

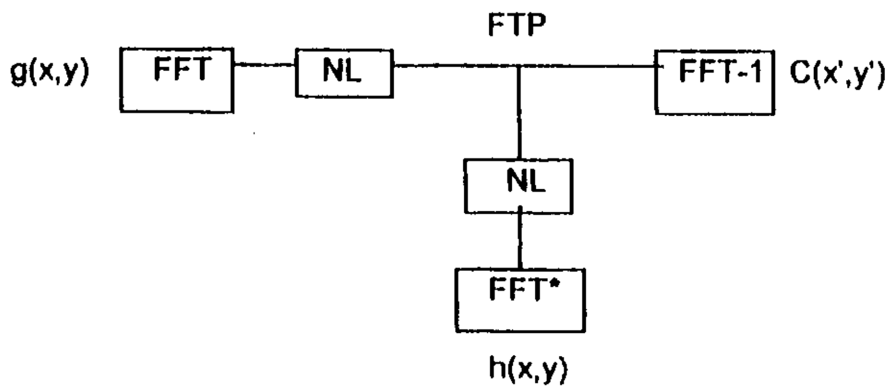
* introduction
* real-time optical correlators (problems to solve)
* performance criteria
* various filters
* dual nonlinear correlation
* application of correlation methods (examples)
* optical associative memory
* orthonormalization of stored images
* optical associative memory with MACE filter
* single-rail optical associative memory
* conclusions

Warsaw University

OPTICAL CORRELATOR

4f optical processor

Input plane $g(x,y)$
filter plane $G(u,v)H^*(u,v)$
correlation plane
$g(x',y') \otimes h(x',y')$



Warsaw University

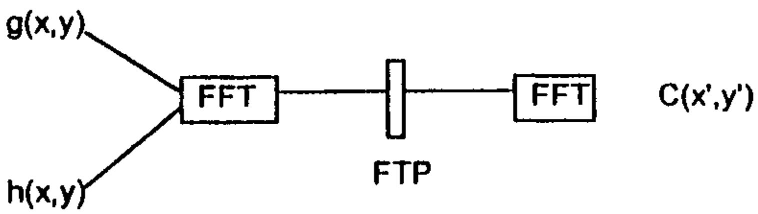
OPTICAL CORRELATOR

Joint transform correlator

Input plane $g(x,y)+h(x,y)\,g(x,y)+h(x,y)$

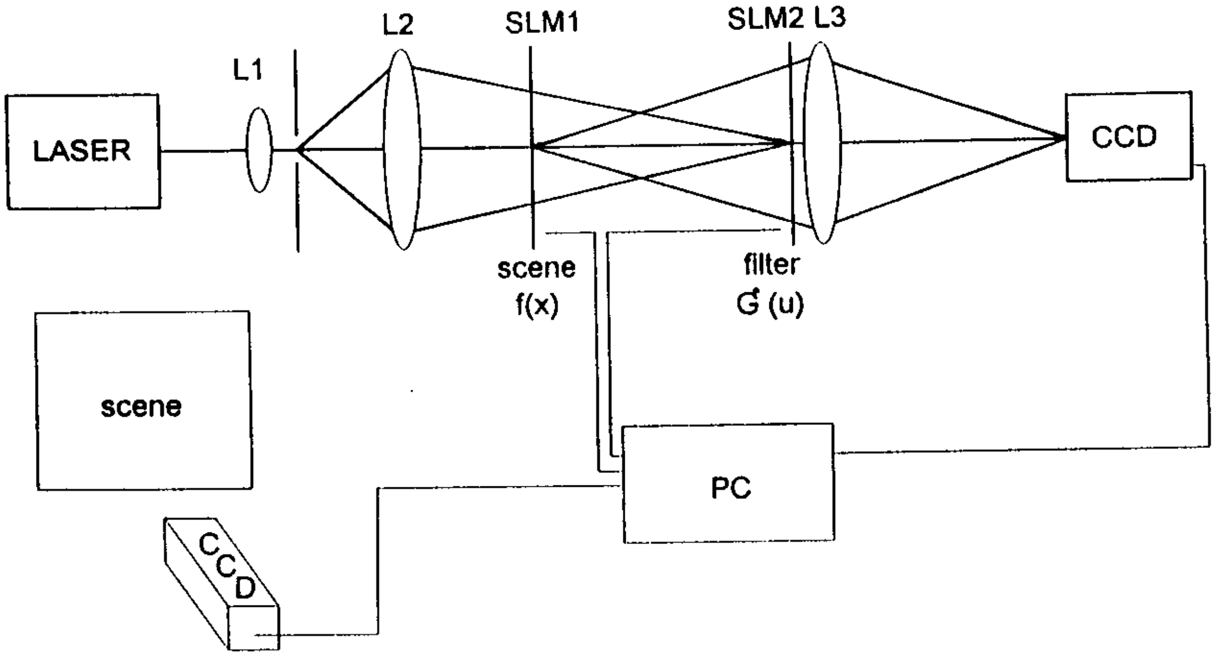
Filter plane $\left|G(u,v)+H(u,v)\right|^2$

Correlation plane $g(x',y')\otimes h(x',y')$



REAL-TIME OPTICAL CORRELATORS

4f architecture

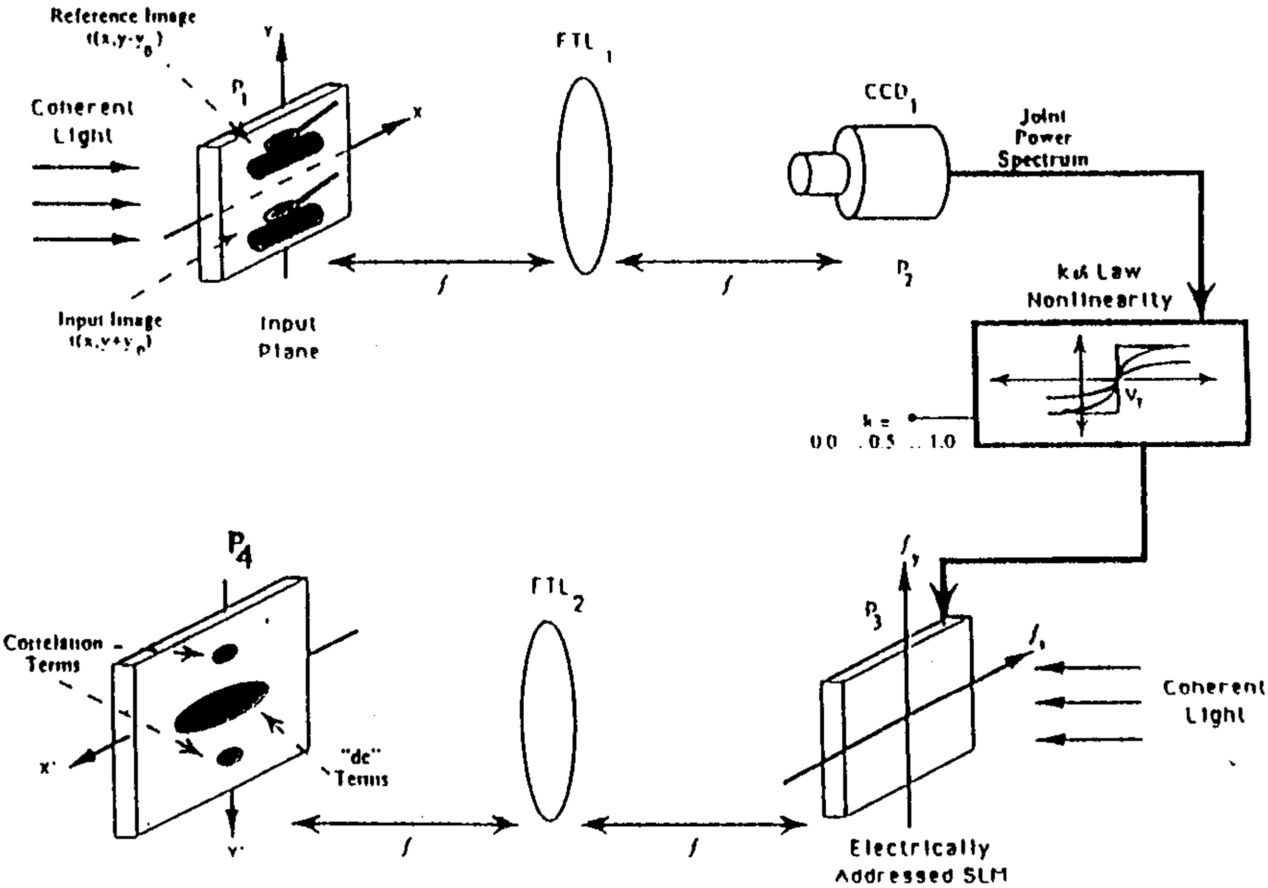


Warsaw University

REAL-TIME OPTICAL CORRELATOR

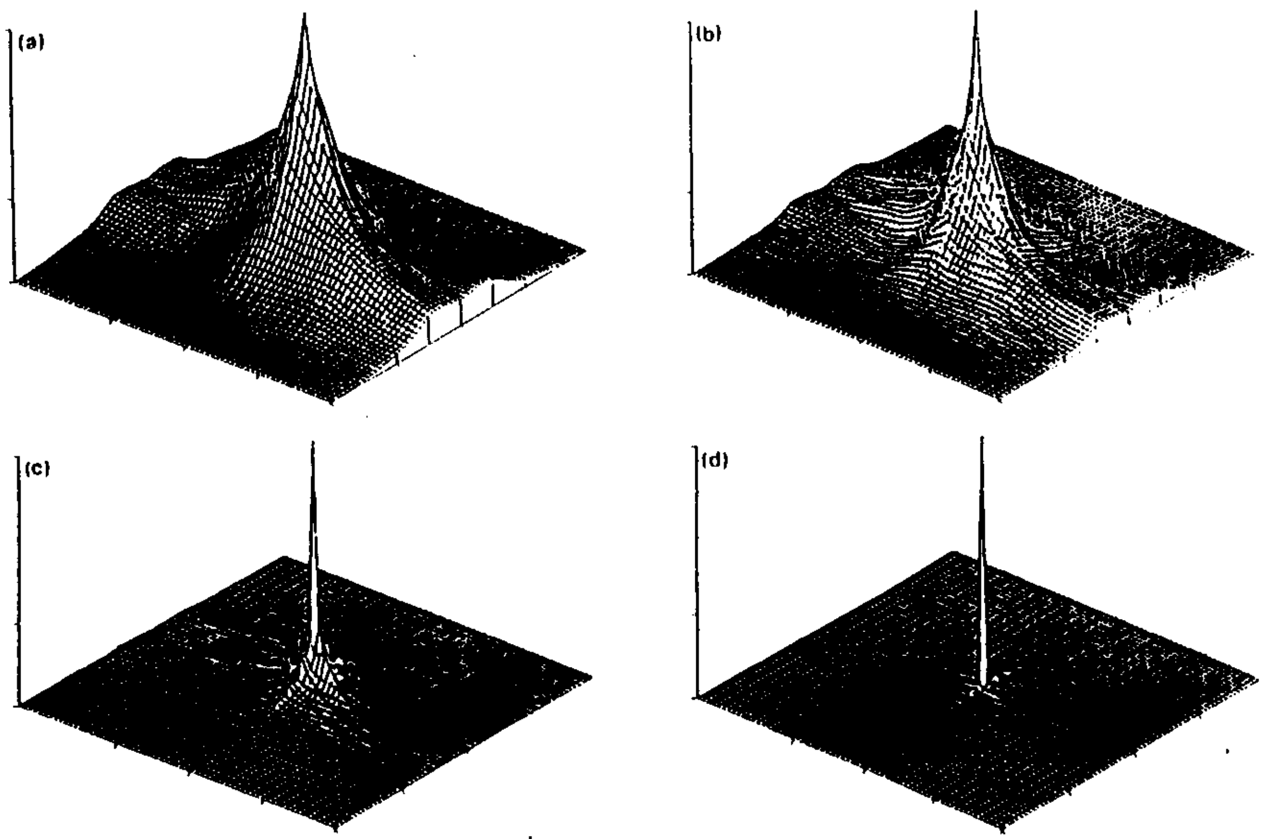
Joint transform architecture

B.Javidi, Opt.Eng. (1990)



Warsaw University

OUTPUT PEAK



Warsaw University

PROBLEMS TO SOLVE

filter encoding

light efficiency

discrimination capability

between-class or intra-class discrimination

output peak location

false alarms

invariance (rotation, scale, intensity, distortion)

SLM and CCD parameters

Warsaw
University

PERFORMANCE CRITERIA

Signal-to-noise-ratio
Peak-to-correlation-energy-ratio
peak location accuracy
light efficiency
discriminability
distortion invariance

Warsaw
University

VARIOUS FILTERS

one reference target

CMF
POF
IF
FPF
LNMF

training set

SDF
MVSDF
MACE

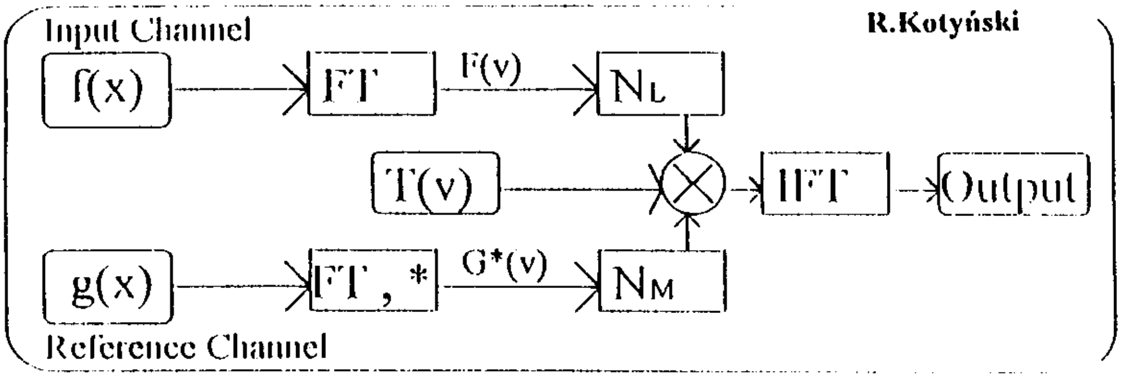
NONLINEAR METHODS

PPC, PEC, SPOF
NJTC
OF

MULTICRITERIA OPTIMIZATION

MINACE
TRADE-OFF FILTERS

DUAL NONLINEAR CORRELATION



$$N_L\left[F(u)\right] = \left|F(u)\right|^L \exp\left[i\varphi(u)\right]$$

$$DNC_{L,M}\{f(x), g(x)\} = IFT\left\{N_L\left[F(u)\right] N_M\left[G^*(u)\right]\right\}$$

$$= IFT\left\{\left|R(\bar{v})\right|^{L+M} \cdot T(\bar{v})\right\}$$

Filter	CMF	POF	IF	FPF	PPC	OF
L	+1	+1	+1	+1	0	-1
M	+1	0	-1	any	0	+1

Warsaw University

PEAK-TO-CORRELATION-ENERGY

B.V.V.Kumar and
L.Hassebrook (1991)

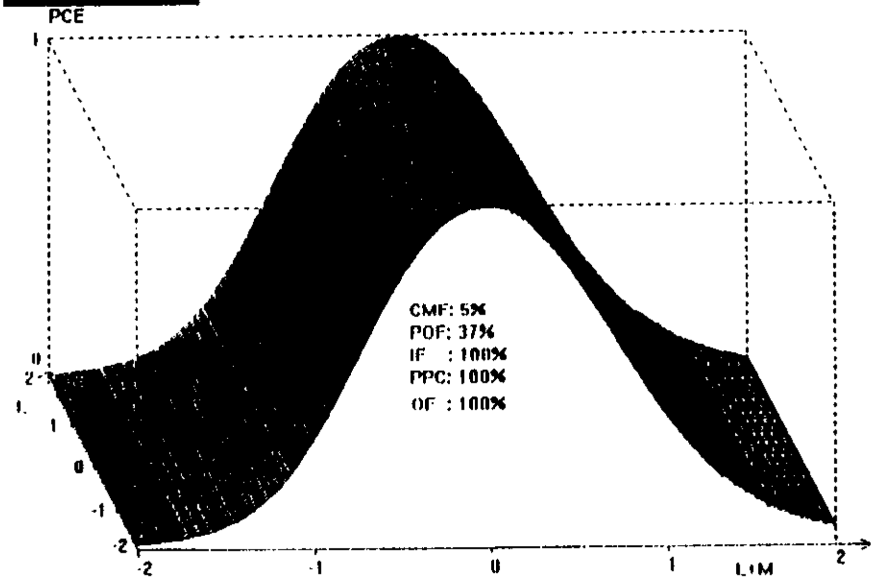
$$\mathrm{PCE} = \frac{|C(0,0)|^2}{E_C}$$

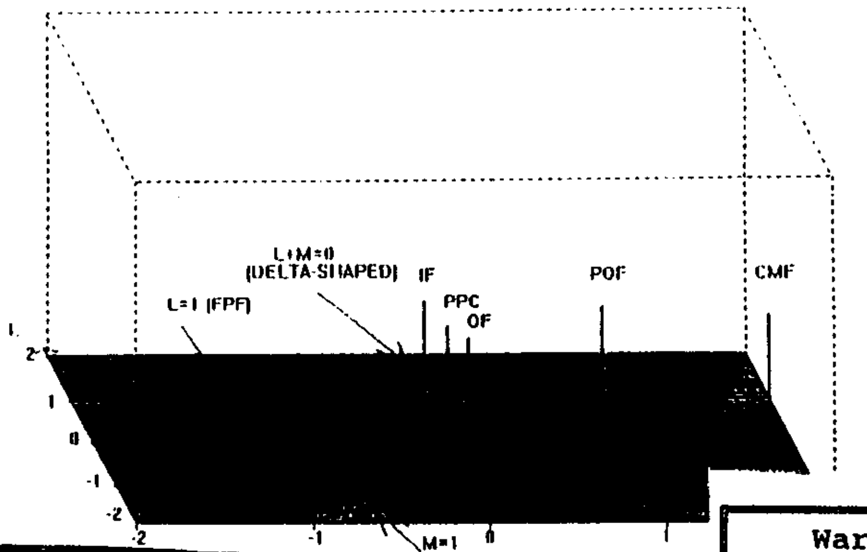
$$E_C = \iint |C(x,y)|^2 \, dx \, dy$$

$$\mathrm{PCE} = \frac{\left[\iint S(u,v)\, H(u,v)\, du\, dv\right]^2}{\iint |S(u,v)|^2 \, |H(u,v)|^2 \, du\, dv}$$

Warsaw
University

PEAK-TO-CORRELATION ENERGY

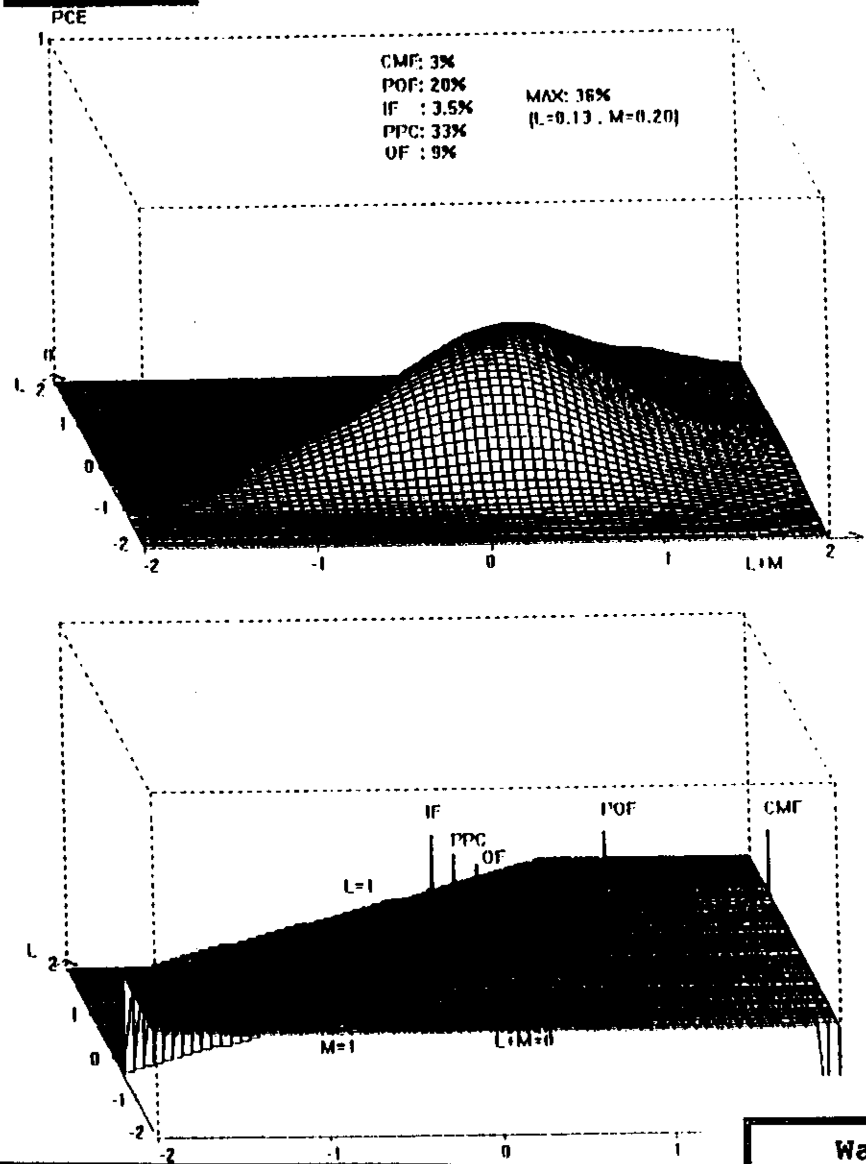




Warsaw University

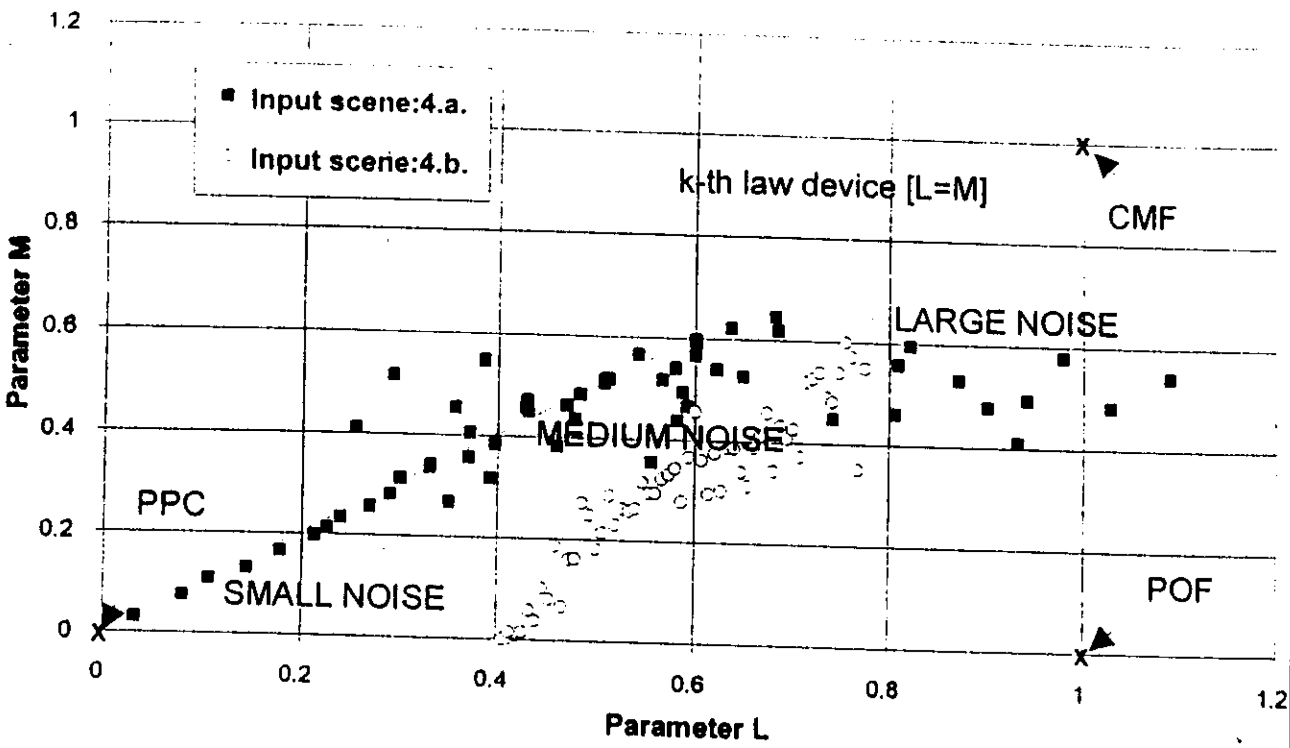
EA

PEAK-TO-CORRELATION ENERGY



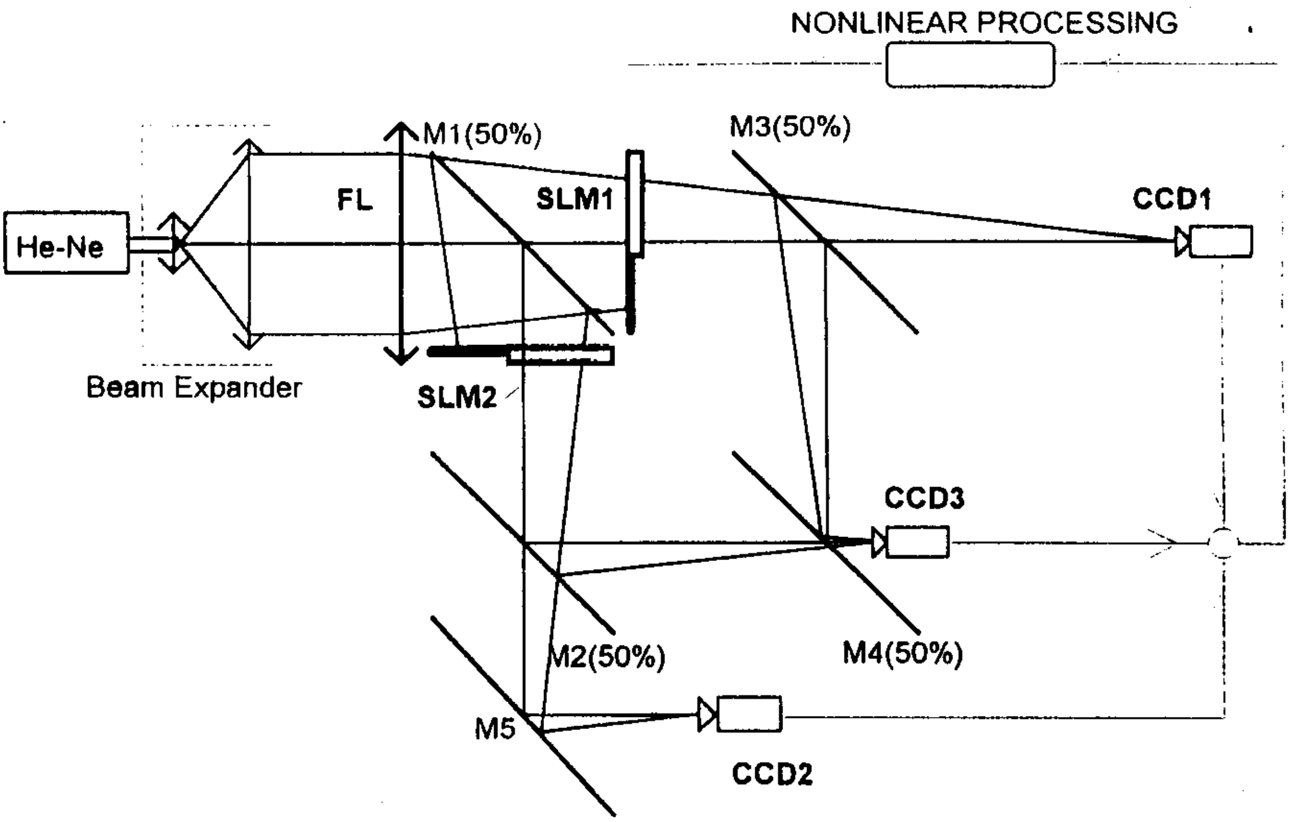
Warsaw University

DNC + NOISE
PCE CRITERION
CHOICE OF PROPER METHOD



Warsaw University

DNC
OPTOELECTRONIC IMPLEMENTATION



Warsaw University

REAL-TIME OPTICAL CORRELATORS
OPTOELECTRONIC IMPLEMENTATION

USA

California Institute of Technology, Pasadena
(D.Psaltis et all.)

Electrical and Computer Eng. Department
Pensylvania State University
(Francis T.S.Yu et all.)

University of Connecticut
(B.Javidi et all.)

Rome Air Development Center
Hanscom Air Force Base
(J.Horner et all.)

U.S.Army Missile Command
Redstone Arsenal
(Don A.Gregory et all.)

Hughes Research Laboratories

San Diego State University
(J.A.Davis et all.)

Warsaw
University

NASA Johnson Space Center
Tracking and Communication Division
(R.D.Juday et all.)

CANADA

Laval University
(H.H.Arsenault et all.)

ISRAEL

Tel-Aviv University
(E.Marom et all.)

Israel Institute of Technology, Haifa
(J.Rosen, J.Shamir et all.)

POLAND

Warsaw University
(K.Chalasinska-Macukow, T.Szoplik)

FRANCE

Thomson-CSF, Central Laboratory, Orsay
(H.Rajbenbach et all.)

University of Franche-Comte, Besancon
(C.Gorecki et all.)

University of Haute Alsace, Mulhouse
(P.Ambs et all.)

ENST de Bretagne, Brest
(J.L.de Bourgrenet de la Tocnaye et all.)

SPAIN

University of Barcelona
(S.Valmitjana et all.)

Autonomous University of Barcelona
(M.J.Yzuel, J.Campos)

A HIGH SPEED HYBRID OPTICAL/DIGITAL CORRELATOR SYSTEM

BRITE-EURAM PROJECT : RY1

PROJECT VALUE = 1 MECU

PROJECT PARTNERS & RESPONSIBILITIES

UNIVERSITY OF GLASGOW – COORDINATOR

- Digital Sub-System
- Electro Optic Sub-Systems
- Software Engineering
- System Integration
- Experimental Work
- Project Management

UNIVERSITY OF NEUCHATEL

- Phase Modulating SLM
- Diffractive Optical Elements

THOMSON CSF/LCR

- Algorithms

UNIVERSITY OF GENOVA

- Algorithms

BRITISH AEROSPACE

- Simulation of SLM Degradations and Bragg Matching Effects

PROJECT ENDORSERS

- Alenia-Aeritalia & Selenia S.p.A.
- Rover Group
- Incorporated Technologies Ltd
- Malvern DRA

ESPRIT Project number 2288

NAOPIA:

New Architectures for Optical Processing in Industrial Applications:

An optical photorefractive correlator for robotic applications

H. Rajbenbach, S. Bann, Ph. Refregier, P. Joffre, J.P. Huignard

Thomson-CSF, Laboratoire Central de Recherches

Domaine de Corbeville, F-91404 Orsay, France

Tel: 33-1-60-19-76-56

Telex: THOM 616 780 F

Fax: 33-1-60-19-74-16

H.St. Buchkremer

KRUPP Forschungsinstitut, Fried Krupp Gmbh

Münchener Straβe 100, D-4300 Essen, Germany

Tel: 49-201-188-30-12

Telex: 857-385 FKES D

Fax: 49-201-188-25-77

A.S. Jensen, E. Rasmussen

RISØ National Laboratory

P.O. Box 49, DK-4000 Roskilde, Denmark

Tel: 45-42-37-12-12

Telex: 43116

Fax: 45-42-37-39-93

K.H. Brenner, G. Lohman

Universität Erlangen-Nürnberg

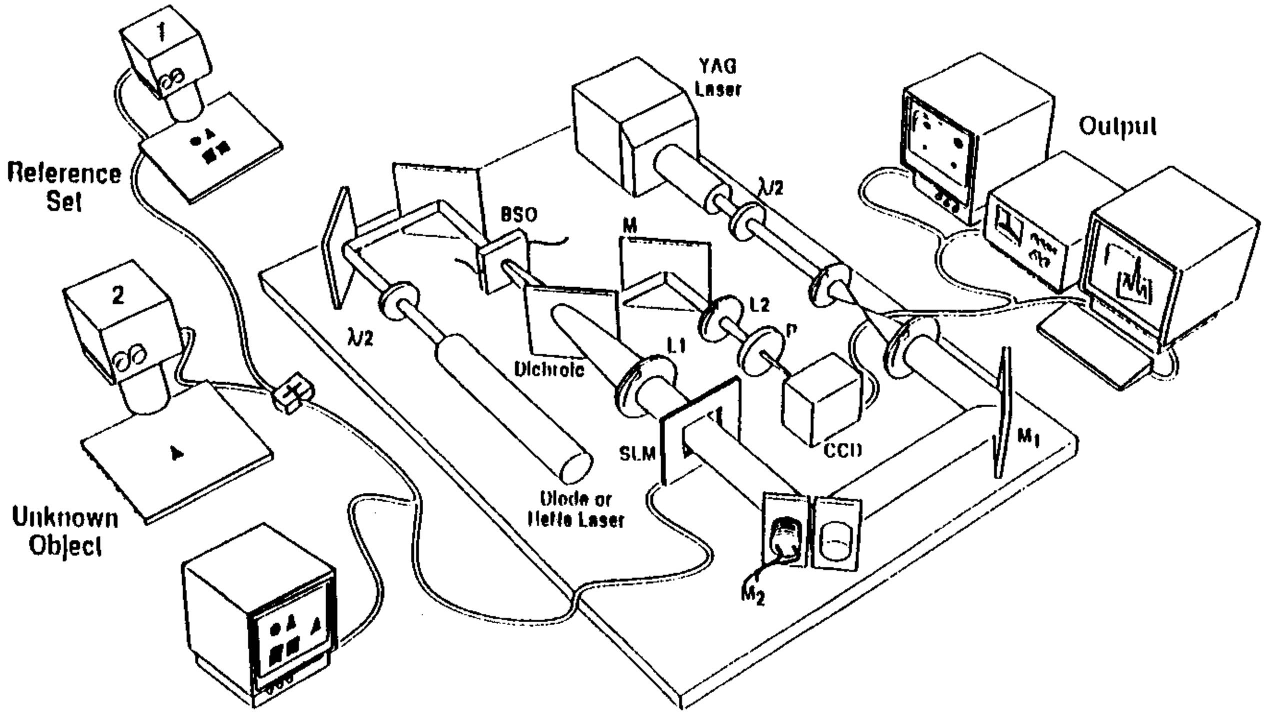
Physikalisches Institut Abt-V

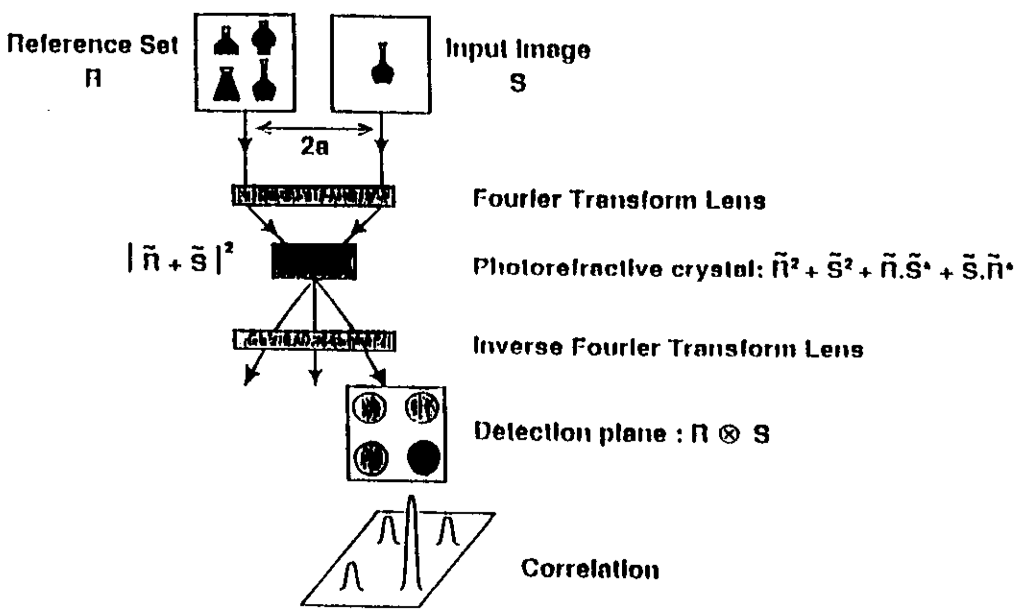
Erwin-Rommel Str. 1, D-8520 Erlangen, Germany

Tel: 49-913-185-77-01

Telex: 629 830 unier d

Fax: 49-913-113-508


1
Reference Set
2
Unknown Object
YAG Laser
λ/2
Output
BSO
M
λ/2
Dichroic
L1
L2
P
SLM
CCD
M_1
Diode or HeNe Laser
M_2


Reference Set
R
Input Image
S
2a
Fourier Transform Lens
$|\tilde{R} + \tilde{S}|^2$
Photorefractive crystal: $\tilde{R}^2 + \tilde{S}^2 + \tilde{R}.\tilde{S}^* + \tilde{S}.\tilde{R}^*$
Inverse Fourier Transform Lens
Detection plane : $R \otimes S$
Correlation

COMPACT OPTICAL CORRELATOR FOR ROADSIGN RECOGNITION

L. Guibert, G. Keryer*, P. Pellat-Finet and J.L. de Bougrenet de la Tocnaye

Groupe Optique et Systèmes de Communication
ENST de Bretagne, BP 832, 29285 Brest Cedex, France
fax: (33) 98.00.10.98

* Groupe Traitement du Signal
Ecole Navale, Lanvéoc-Poulmic, 29240 Brest NAVAL, France

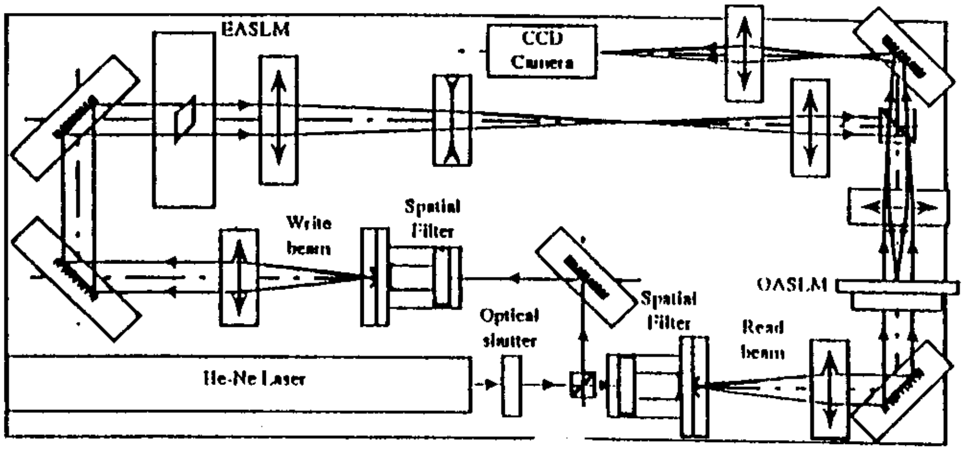
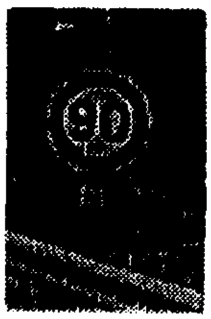
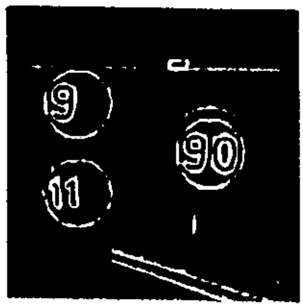


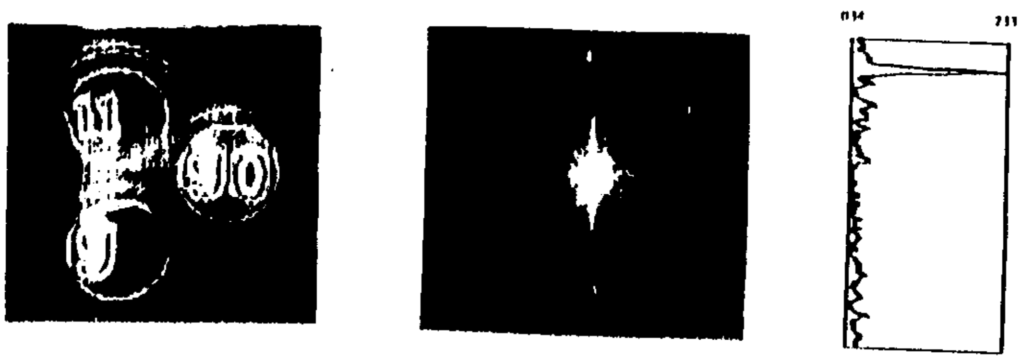
Figure 2: Optical set-up

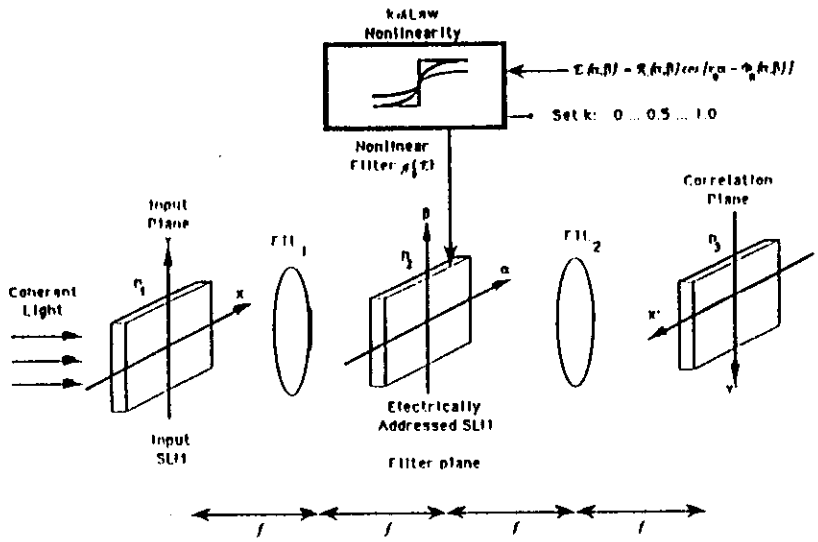


Observation window

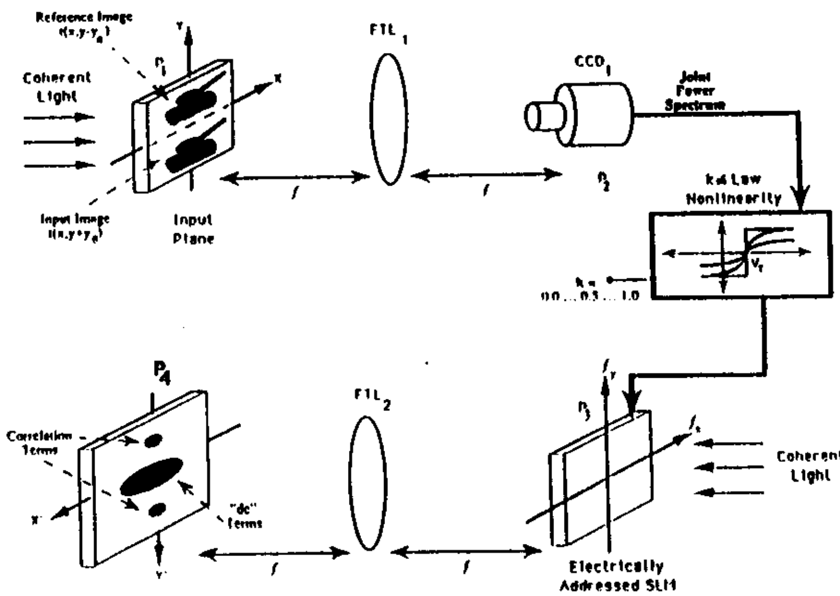


Input plane




k th Law
Nonlinearity
Set k: 0 ... 0.5 ... 1.0
Nonlinear
Filter
Correlation
Plane
Input
Plane
FTL 1
FTL 2
Coherent
Light
Electrically
Addressed SLM
Input
SLM
Filter plane
f
f
f
f

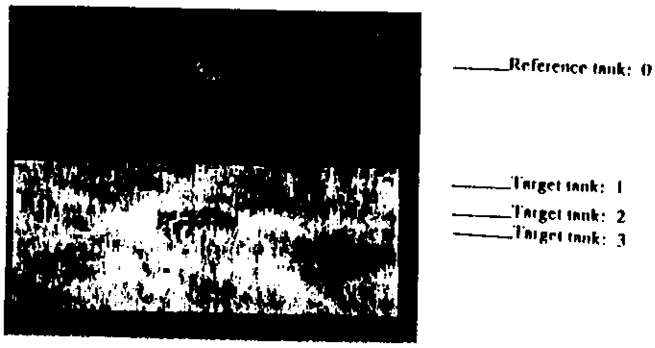
(a)

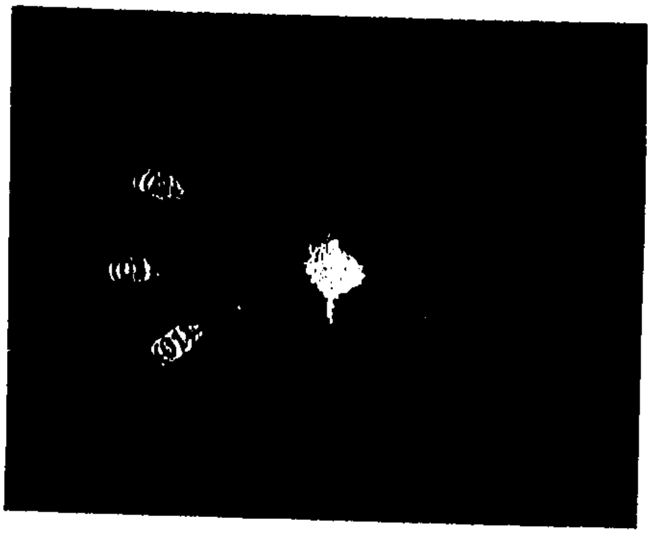

Reference Image
FTL 1
CCD 1
Joint
Power
Spectrum
Coherent
Light
Input Image
Input
Plane
k th Law
Nonlinearity
f
f
P_4
FTL 2
Correlation
Terms
"dc"
Terms
Coherent
Light
f
f
Electrically
Addressed SLM

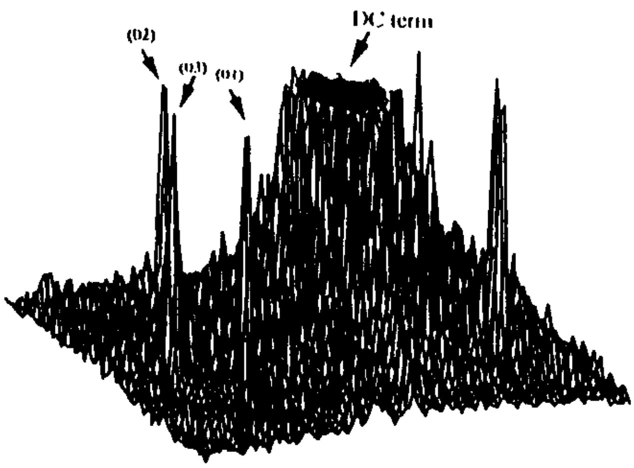
(b)

EXPERIMENTAL RESULTS

B.Javidi







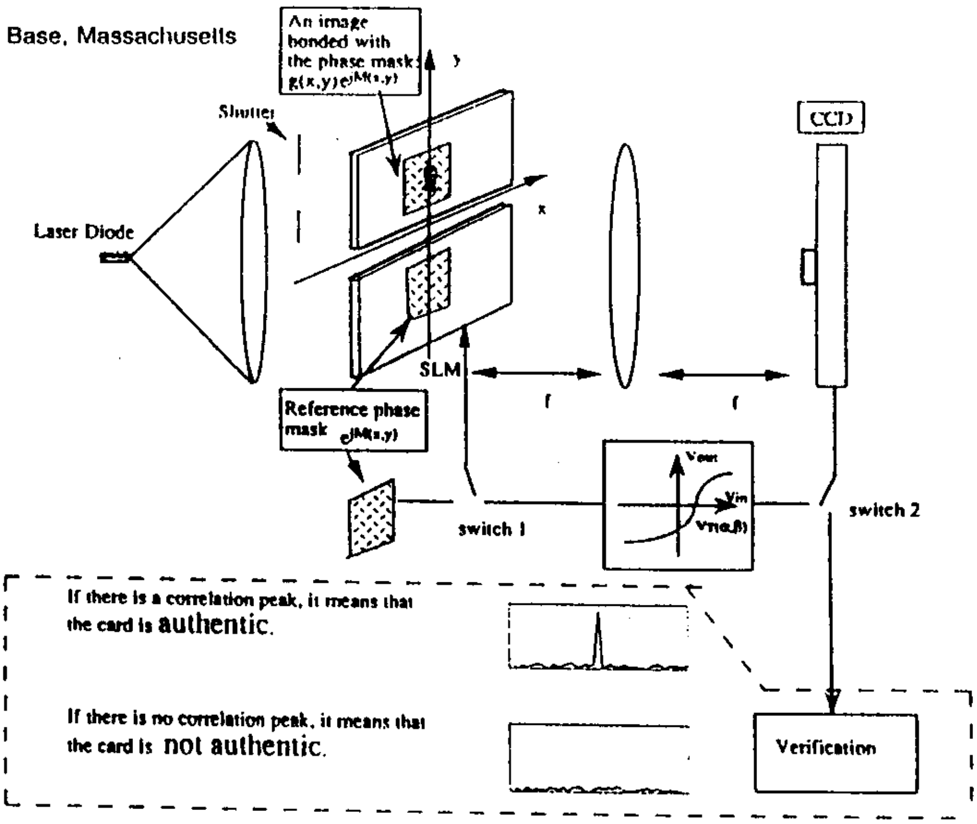
(27)

Optical pattern recognition for validation and security verification

Bahram Javidi, FELLOW SPIE
University of Connecticut
Department of Electrical and Systems Engineering
U-157
Storrs, Connecticut 06269-3157
E-mail: bahram@brc.uconn.edu

Joseph L. Horner, FELLOW SPIE
Rome Laboratory
Hanscom Air Force Base, Massachusetts 01731

$$i(x,y) = g(x,y)\ \exp[jM(x,y)]$$



Warsaw University

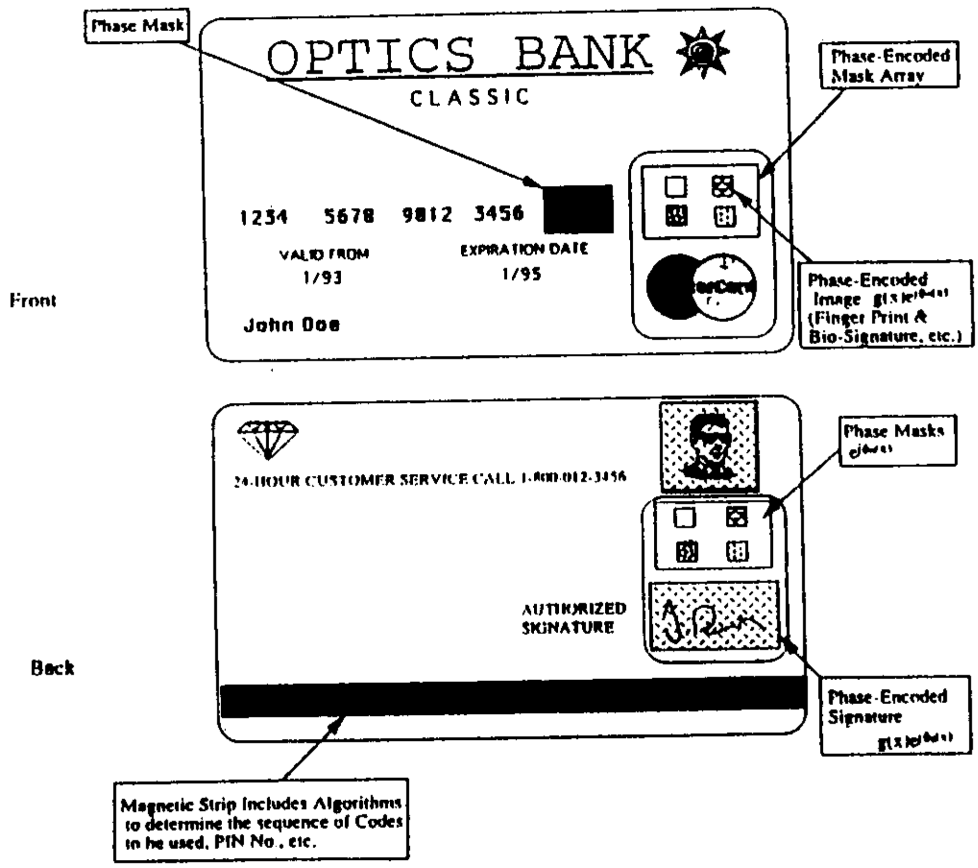


Fig. 3 Example of the phase-encoded ID card inserted into the correlator of Fig. 2.

Warsaw University

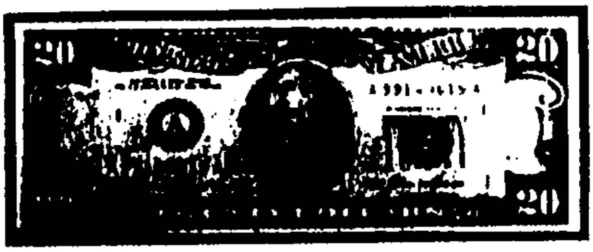
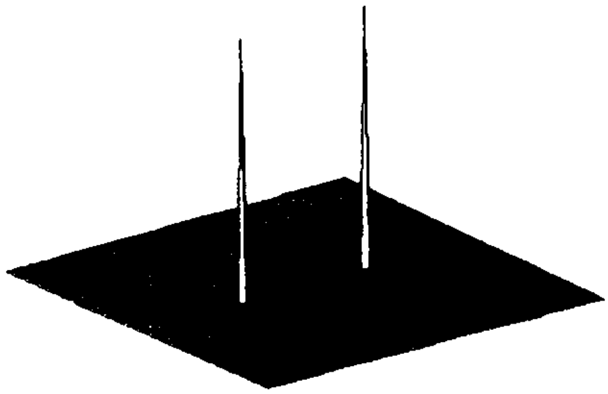
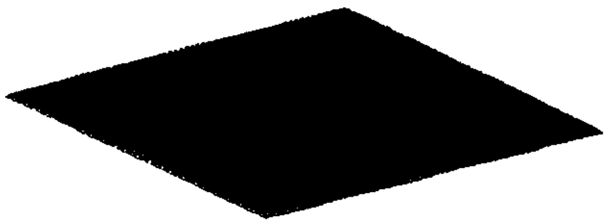


Fig. 5 Input image (a $20 bill) used in the simulations. A phase mask is placed over the image of Andrew Jackson.



(a)

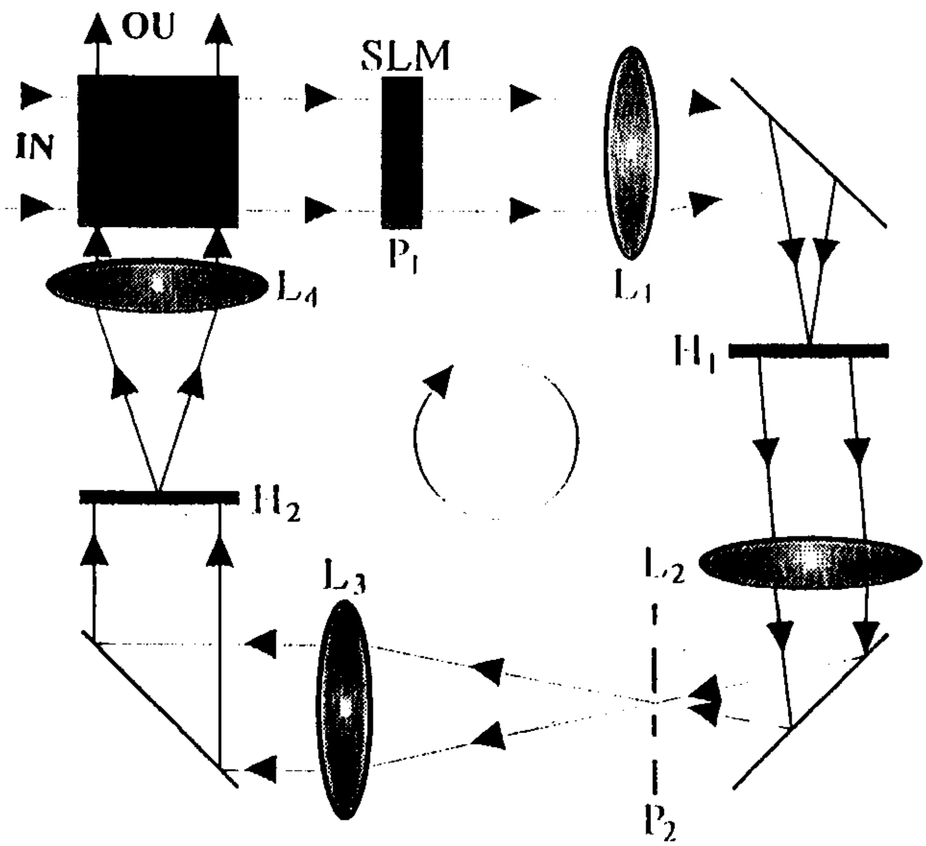


(b)

Fig. 6 Computer correlation simulation with Fig. 5 as input: (a) the reference function is the random phase mask and (b) the reference function is a different random phase mask, for example, a counterfeit mask.

OPTICAL ASSOCIATIVE MEMORY
CASCADE OF CORRELATORS

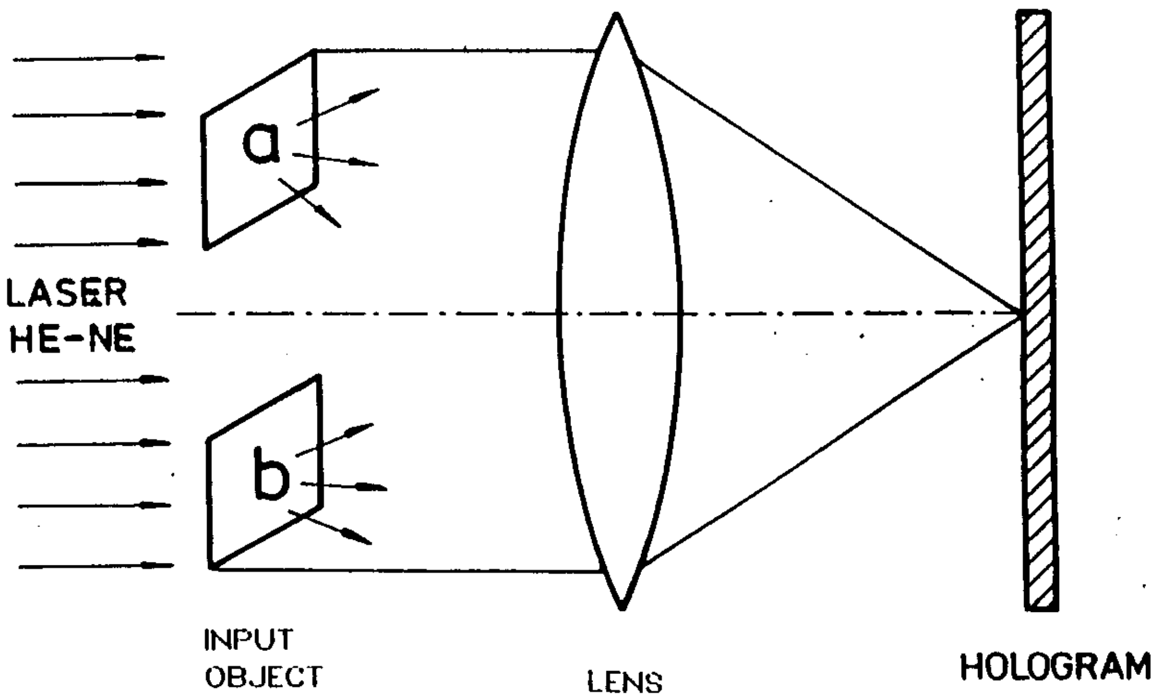
D.Psaltis



Warsaw University

FOURIER HOLOGRAM.

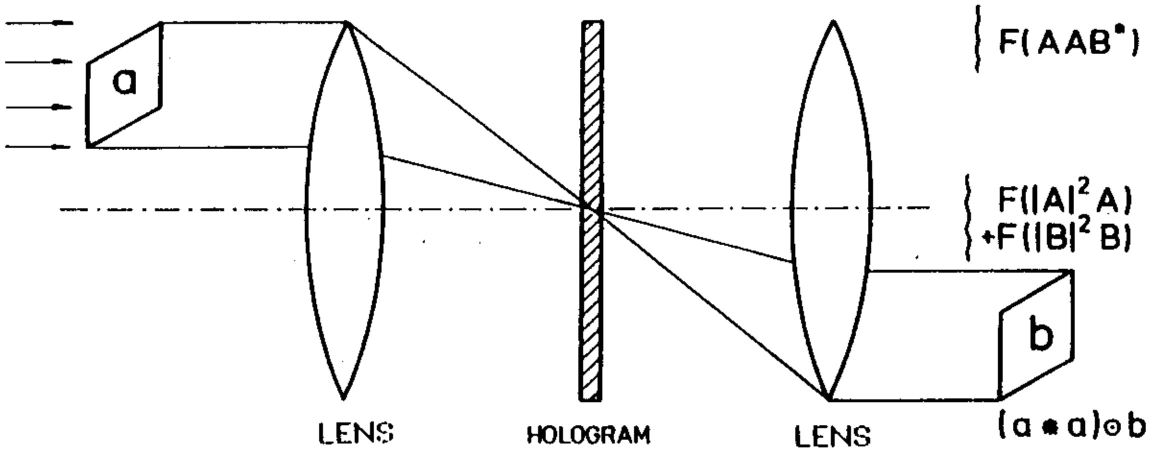
$$T(u,v) = |A(u,v) + B(u,v)|^2 = |A(u,v)|^2 + |B(u,v)|^2 + A(u,v)B^*(u,v) + A^*(u,v)B(u,v)$$



Warsaw University

FOURIER HOLOGRAM.

RECONSTRUCTION

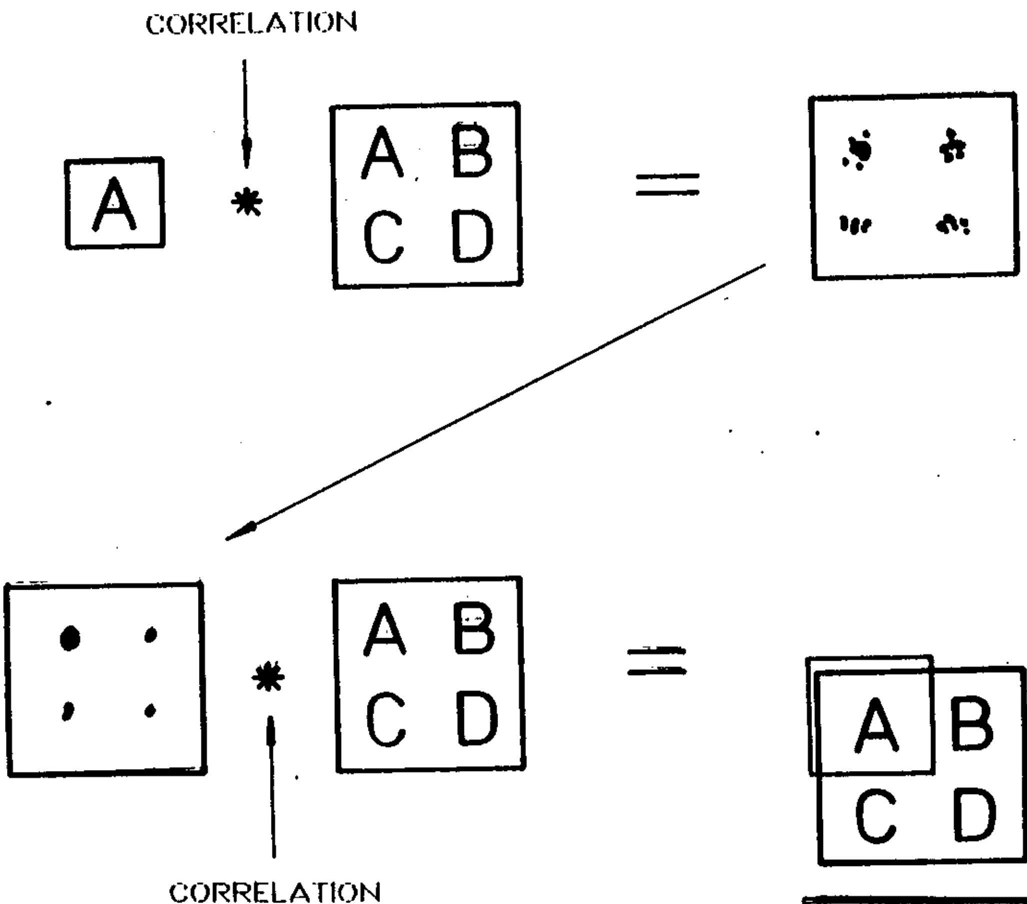


$$A(u,v)T(u,v) = |A|^2A + |B|^2A + AAB^* + AA^*B$$

$$FT[AA^*B] = (a * a) \odot b$$

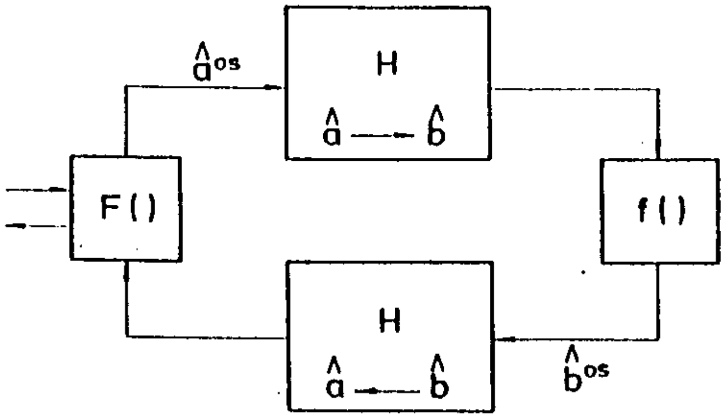
Warsaw University

OPTICAL ASSOCIATIVE MEMORY
RING MEMORY



Warsaw
University

OPTICAL ASSOCIATIVE MEMORY
RING MEMORY

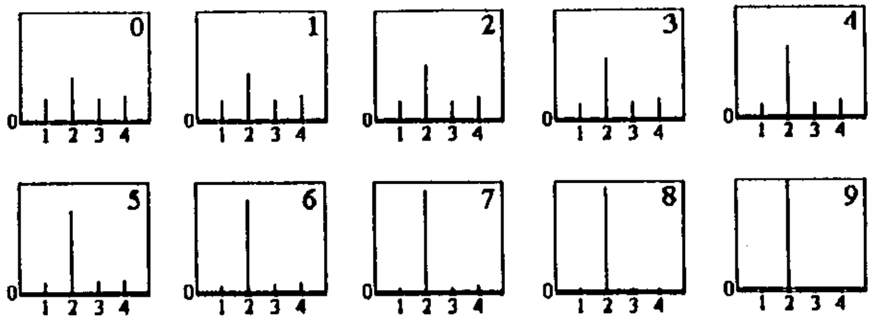


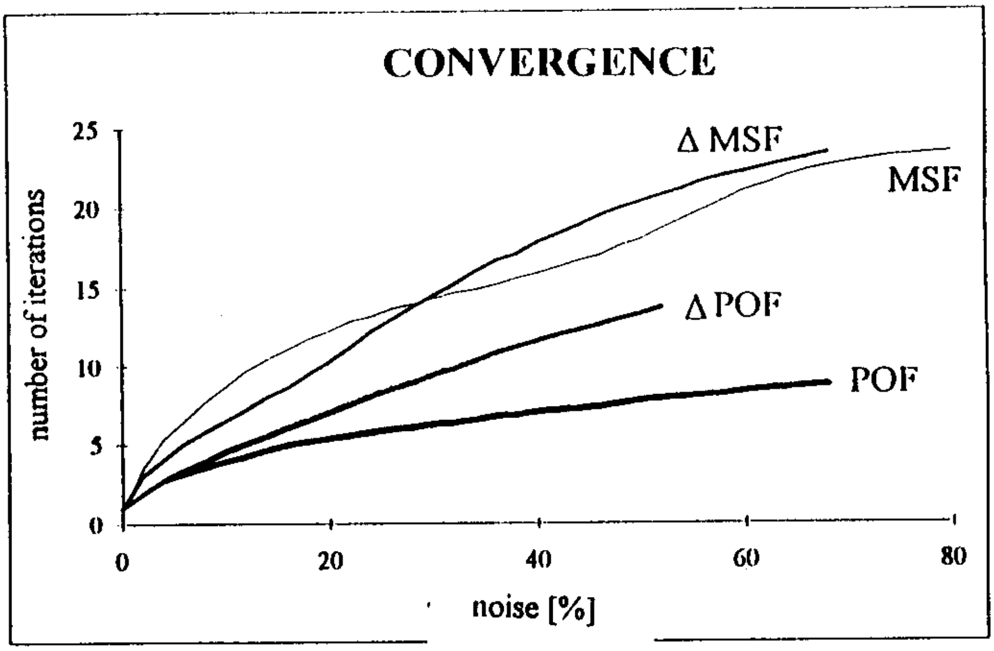
Warsaw University

RING MEMORY
CASCADE OF CORRELATORS

* input signal quality
*first hologram (first layer)
* second hologram (second layer)
* orthonormalization od stored images
(eigenvalues of the system)

Warsaw
University

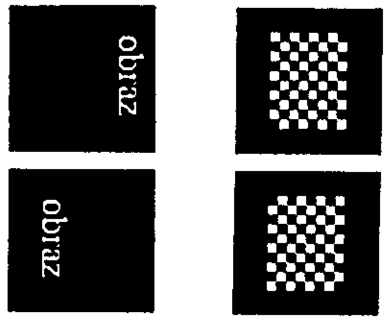




Warsaw University

Orthonormalization procedure for optical resonator neural networks

Edwin Ghahramani
L. Roger B. Patterson
MPB Technologies
Space and Photonics Division
151 Hymus Boulevard
Pointe Claire, Quebec,
Canada H9R 1E9



$$F_m \star \sum_{n=1}^{N} F_n(R_n) \neq \delta_{mn} \qquad \forall R_n \qquad (1)$$

$$F_m \star \sum_{n=1}^{N} F_n(R_n) = \delta_{mn} \qquad \forall R_n \qquad (2)$$

$$F_m \star \sum_{n=1}^{N} T_n(R_n) = \delta_{mn} \qquad \forall R_n \qquad (3)$$

$$T_n = \sum_{k=1}^{N} \xi_{kn} F_n(R_n) \qquad (4)$$

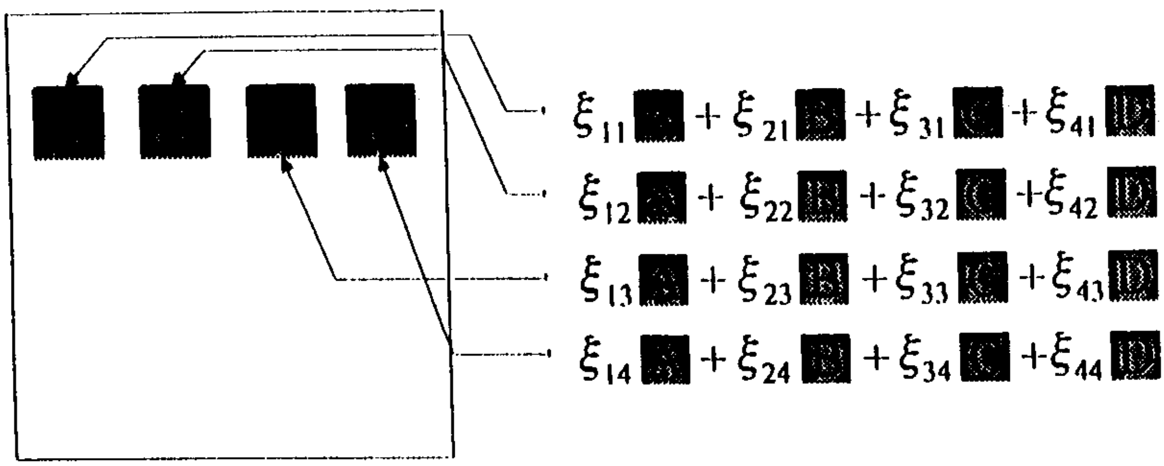
Warsaw University

$$F_m \star \sum_{k=1}^{N}\sum_{n=1}^{N} \xi_{kn} F_n(R_n) = \delta_{mn} \qquad (5)$$

$$\sum_{k=1}^{N} \xi_{kn} P_m = \delta_{mn} \qquad (6)$$

$$P_m = F_m \star \sum_{n=1}^{N} F_n(R_n) \qquad (7)$$

$$\xi P = I \qquad \xi = P^{-1} \qquad (8)$$



Warsaw University

EXPERIMENTAL RESULTS

GHAHRAMANI and PATTERSON

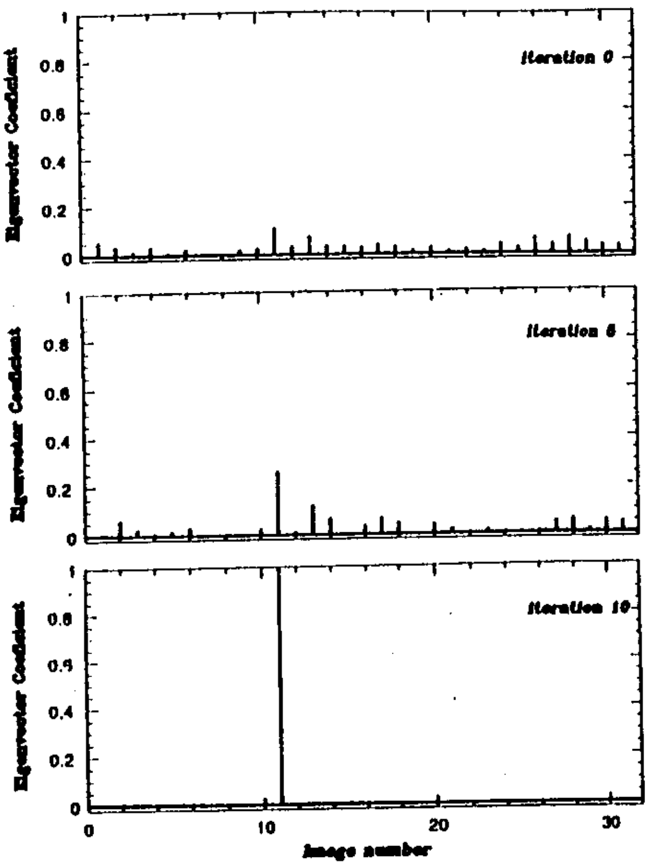


Fig. 6 Corresponding eigenmode coefficients of Fig. 5. The coefficients are presented in normalized units of intensity.

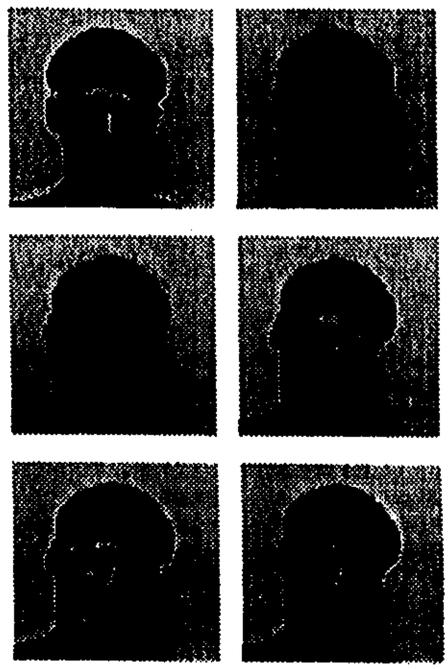
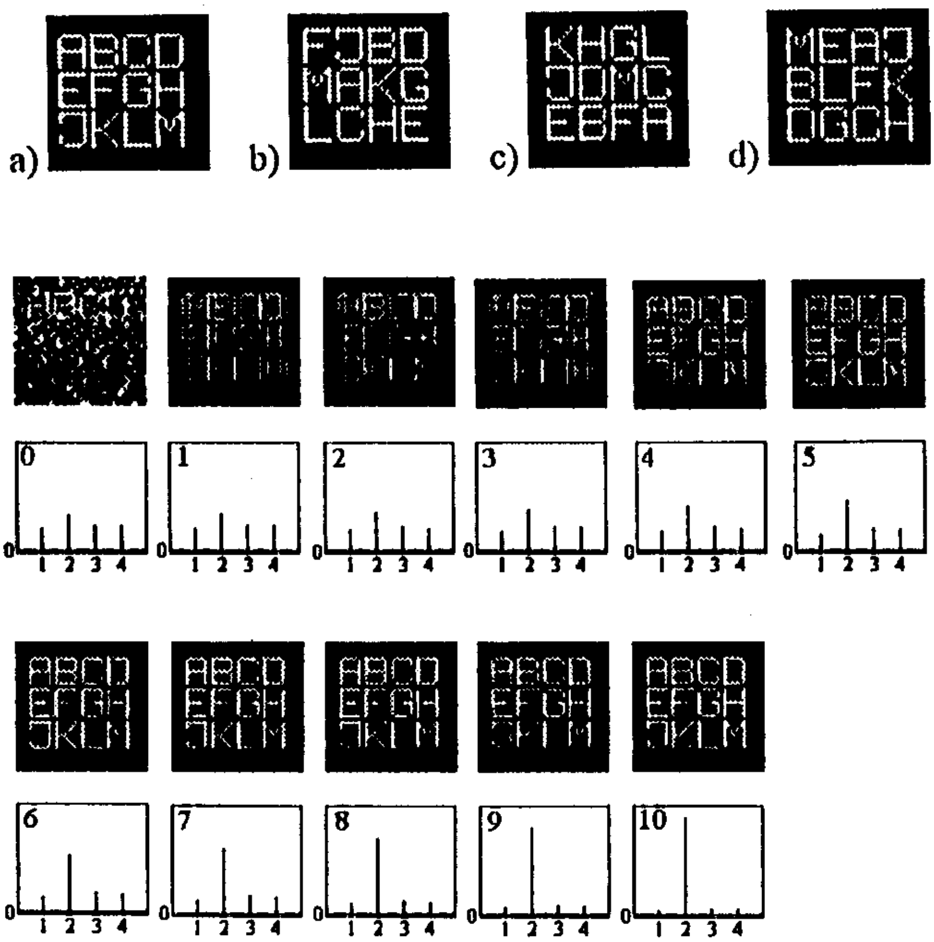


Fig. 8 A disguised (dark sunglasses) and rotated picture (top left) of one of the subjects is used as the input. The results of the successive odd iterations are shown. After 9 iterations the correct image (bottom right) is recovered.

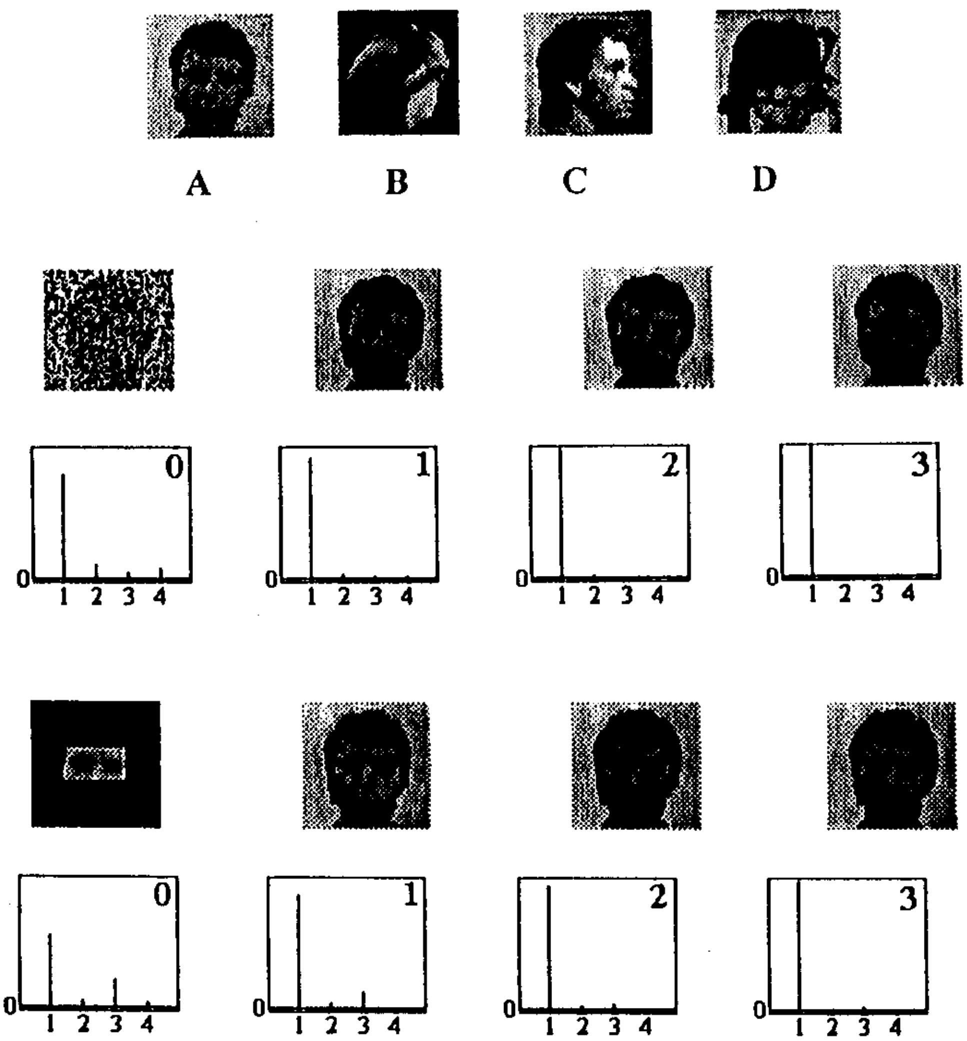
Warsaw University

NONORTHOGONAL BINARY IMAGES



Warsaw University

NONORTHOGONAL GRAY LEVEL IMAGES
+
ORTHONORMALIZATION

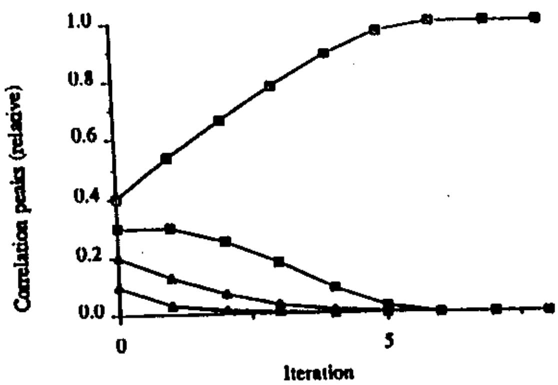


Warsaw
University

Incoherent optical associative memory by using synthetic discriminant function filters

Masaki Taniguchi, Katsunori Matsuoka, and Yoshiki Ichioka

CONVERGENCE



$$\iint_R r_i(x, y) g_j(x, y) \mathrm{d}x\mathrm{d}y = \beta\delta_{ij}$$

$$i, j = 1, 2, \ldots, M,$$

Warsaw University

OPTICAL ASSOCIATIVE MEMORY WITH MACE FILTER

R.Kasztelanic

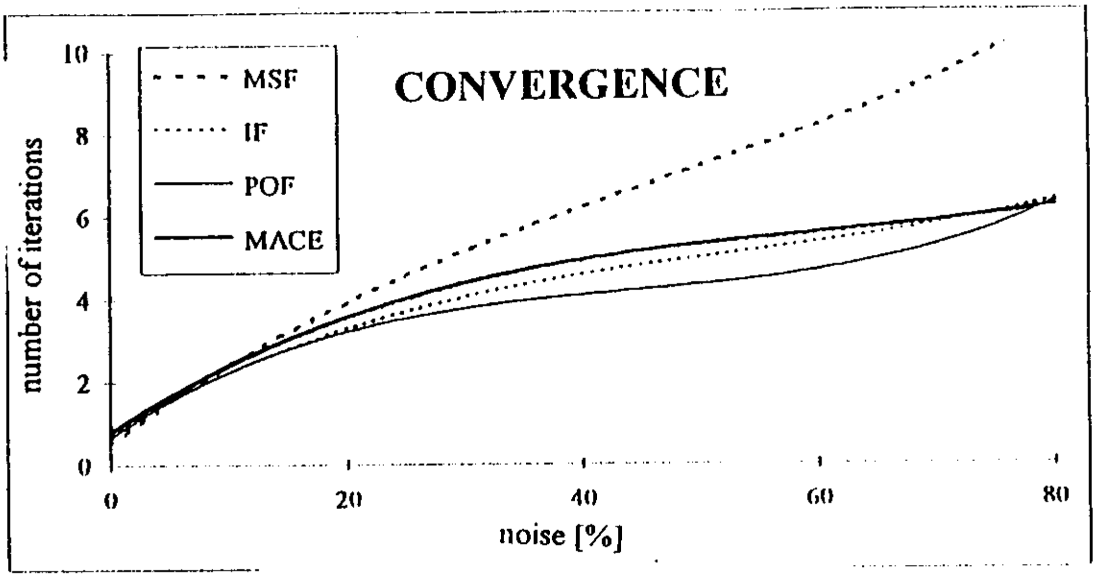
MACE FILTER

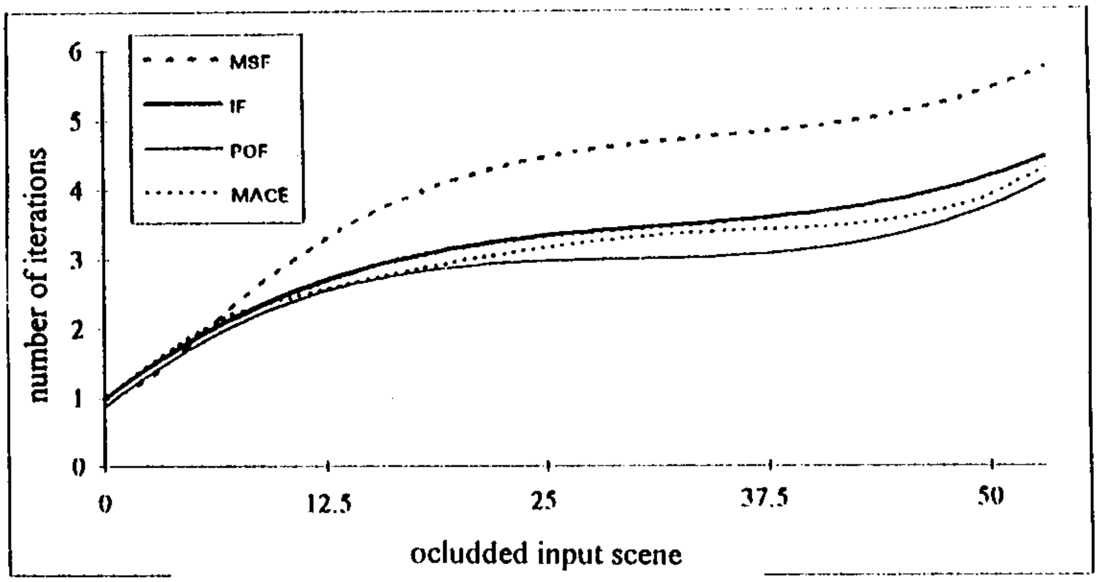
$$H = D^{-1}X(X^{+}D^{-1}X)^{-1}U$$

$$D(k,k) = |X(k)|^2 \quad \Rightarrow \quad D = \begin{bmatrix} |X_1|^2 & 0 & & \\ 0 & |X_2|^2 & 0 & \\ & & \cdot & \\ & 0 & & \cdot \\ & & & |X_n|^2 \end{bmatrix}$$

$$U_i = X_i^{+}H$$

Warsaw University





Warsaw University

Single-rail translation-invariant optical associative memory

Alain Bergeron, Henri H. Arsenault, and Denis Gingras

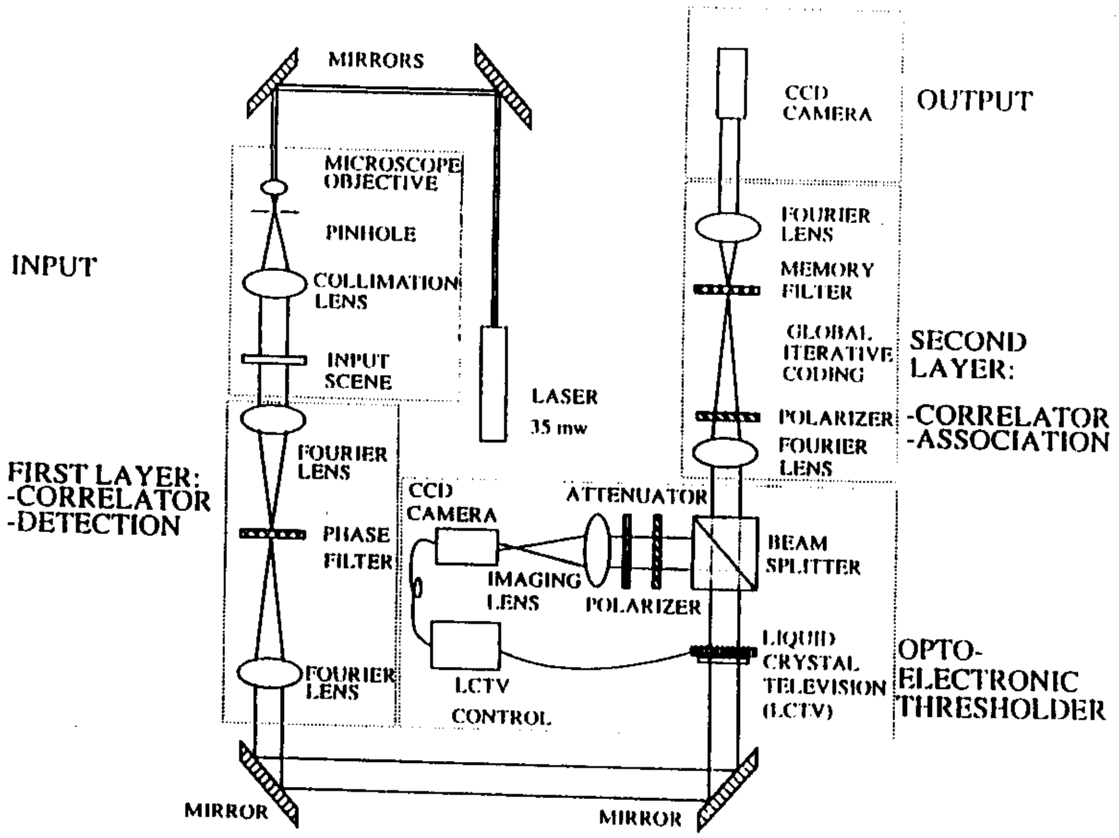


Fig. 1. Optical memory architecture.

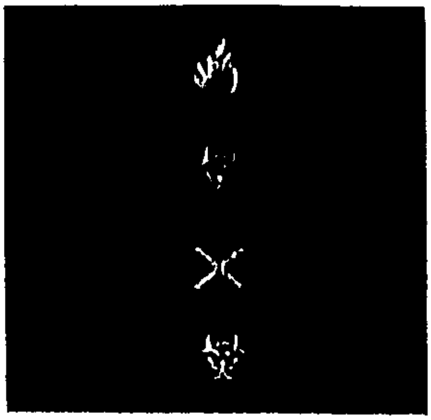


Fig. 3. Input scene. The objects to be detected are the biological hazard symbols (the second and the fourth objects).

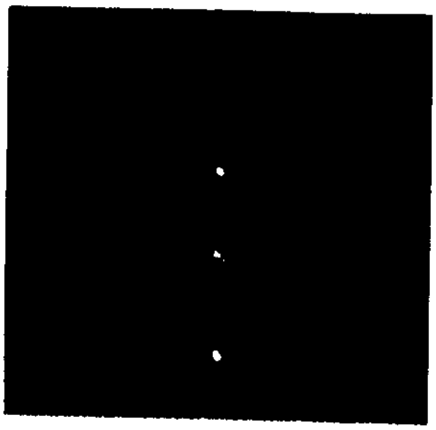


Fig. 4. Correlation of the input scene of Fig. 3 with a phase filter.

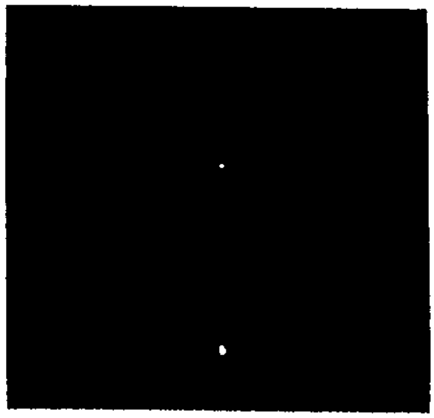


Fig. 6. Thresholded output of the first layer.

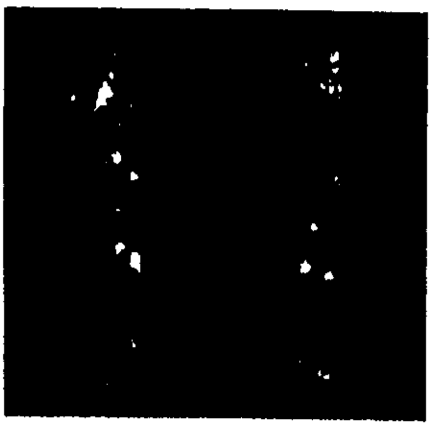


Fig. 5. Output of the associative memory when the optoelectronic module was not in operation.

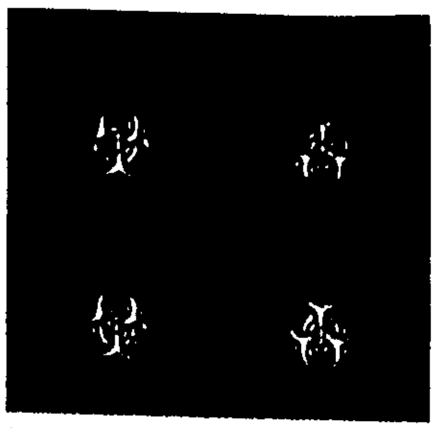


Fig. 7. Associative-memory output when the thresholder is operational for the input scene of Fig. 3.

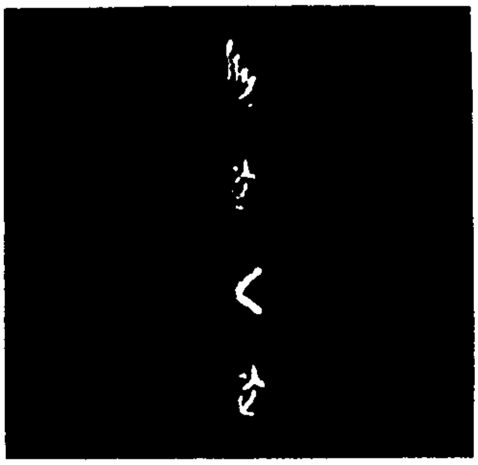


Fig. 9. Input occluded by 50%.

Fig. 10. Associative-memory output for occluded input of Fig. 9.

Warsaw University

".......I've been working in optical information processing since the mid'60 and have been waiting for the SLM that are just becoming available. Unfortunately, now that we have them and can do the experiments, we are finding that the architectures we had in mind, aren't exactly what we needed. on the other hand, since we can now build the systems, there should now be rapid progress in new architectures....."

Thomas Cathey,
director of the University of Colorado's
Optoelectronic Computing Systems Center

PHOTONICS SPECTRA, February 1993

Warsaw
University