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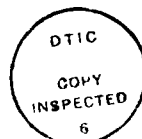
The Center for Night Vision and Electro-Optics

OPTOELECTRONIC WORKSHOPS

II

AUTOMATIC PATTERN RECOGNITION

APRIL 7, 1988



sponsored jointly by

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ARO-URI Center for Opto-Electronic Systems Research
The Institute of Optics, University of Rochester

OPTOELECTRONIC WORKSHOP
ON
AUTOMATIC PATTERN RECOGNITION

**Organizer: ARO-URI-University of Rochester
and Center for Night Vision and Electro-Optics**

- 1. INTRODUCTION**
- 2. SUMMARY -- INCLUDING FOLLOW-UP**
- 3. VIEWGRAPH PRESENTATIONS**
 - A. Center for Opto-Electronic Systems Research**
Organizer -- Nicholas George

Image Science -- Overview
Nicholas George

Diffraction Pattern Sampling
Dennis Venable

Image Retrieval
Robert Rolleston
 - B. Center for Night Vision and Electro-Optics**
Organizer -- Mark Norton
- 4. LIST OF REFERENCES**
- 5. LIST OF ATTENDEES**
- 6. DISTRIBUTION**

1. INTRODUCTION

This workshop on "Automatic Pattern Recognition" represents the second of a series of intensive academic/ government interactions in the field of advanced electro-optics, as part of the Army sponsored University Research Initiative. By documenting the associated technology status and dialogue it is hoped that this baseline will serve all interested parties towards providing a solution to high priority Army requirements. Responsible for program and program execution are Dr. Nicholas George, University of Rochester (ARO-URI) and Dr. Rudy Buser, NVEOC.

2. SUMMARY -- INCLUDING FOLLOW-UP

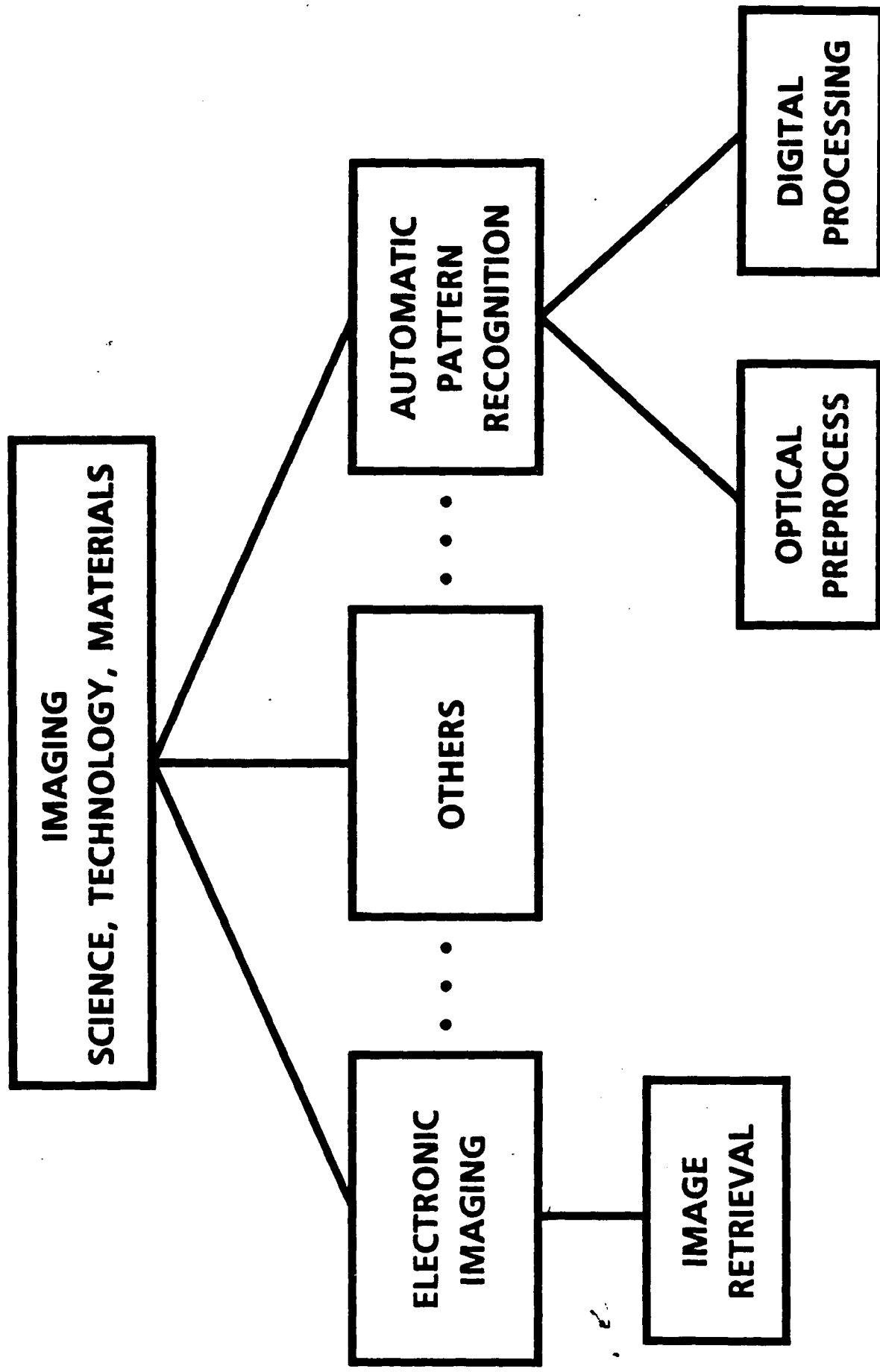
University of Rochester: The workshop group consisted of Professor Nicholas George, Dr. Thomas Stone, Dr. Robert Rolleston (graduated this year - 1988) and Dennis Venable, planning to graduate in 1989.

The main points of briefings by George, Rolleston, and Venable are as follows:

- a. In pattern recognition that is pixal intensive, there is considerable merit in optical preprocessing or a parallel channel of processing that works at high rate coupling in auxiliary data to a more conventional all-digital system. Examples are optical transforms in white light (cosine, sine, Hartley, or Fourier), direct correlation schemes as by Morris at UR, and the neural network models that provide high-speed, parallel computation and are being studied at numerous laboratories.
- b. Various light valve schemes are getting better and better; and as they do it is worthwhile considering coherent diffraction pattern sampling. Some recent classifications or sortings were described.
- c. Image retrieval was described including recent work of Rolleston on Fresnel-zone retrieval.

Imaging of the type simulating current Army objectives in pattern recognition were shown by the Army scientists. There were discussions about UR being able to access these images for test purposes, and we should follow-up on this.

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
IMAGE SCIENCE -- OVERVIEW



Nicholas George
April, 1988

IMAGE SCIENCE

RESEARCH TRENDS

1950 - 60 - 70 - 80 - 85 - 90 - 95 - 2000

WHITE



LASER

MONOCHROMATIC



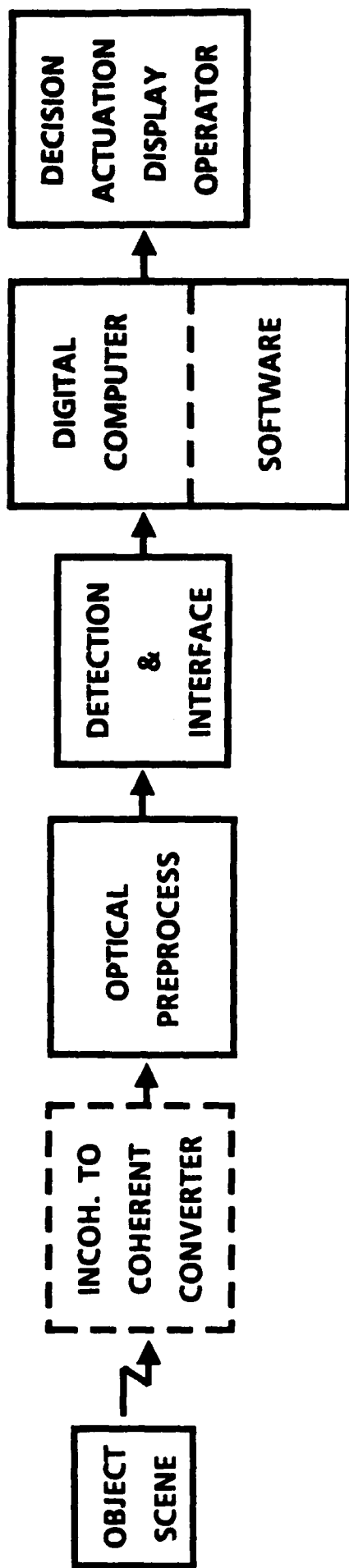
● DEVICES



* WHITE LIGHT

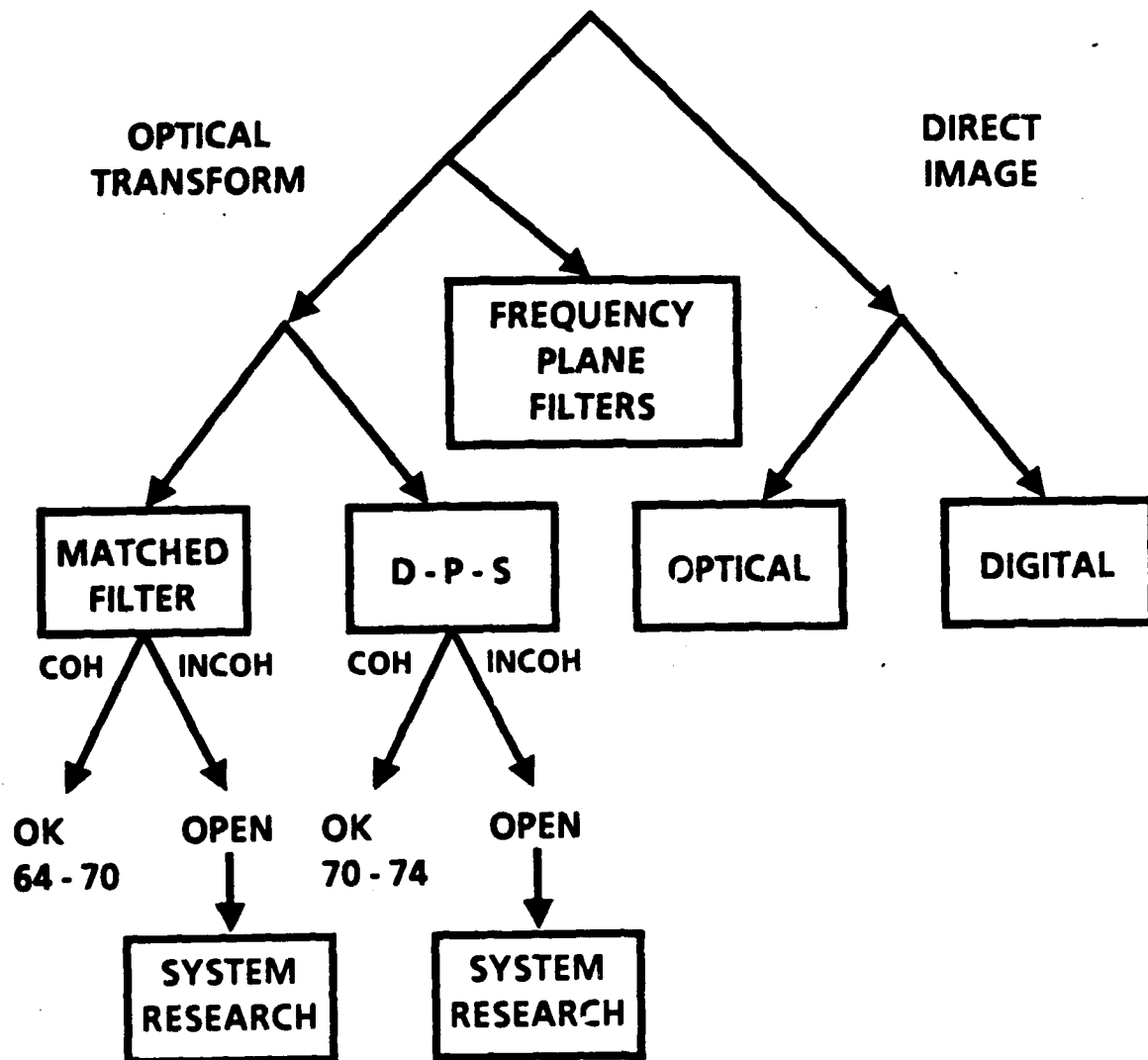
- LIGHT VALVES
- NONLINEAR OPTICAL MEDIA
- PHOTOPOLYMERS, NON AgBr

* SYSTEMS - WHITE LIGHT



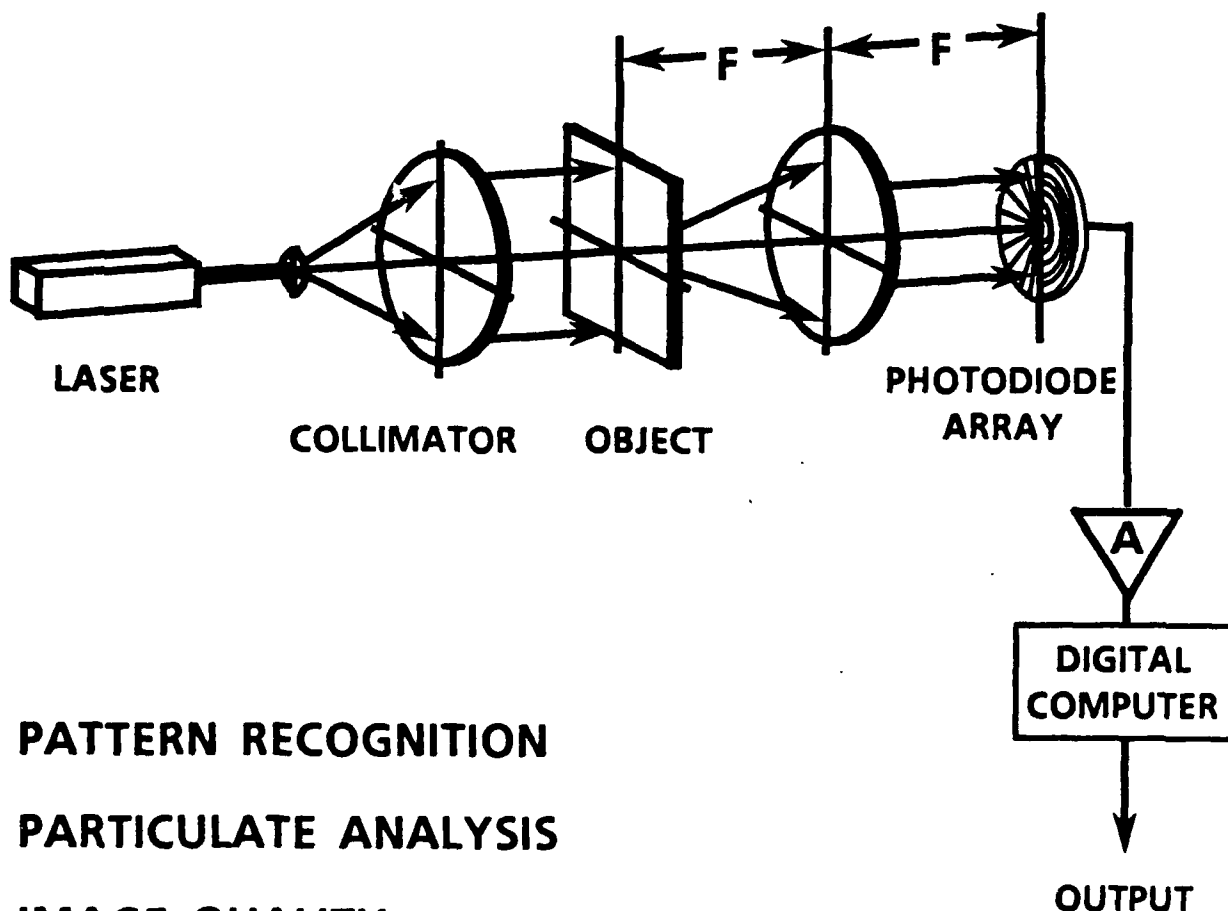
OPTICAL PREPROCESS HYBRID (GENERIC SYSTEM)

AUTOMATIC PATTERN RECOGNITION



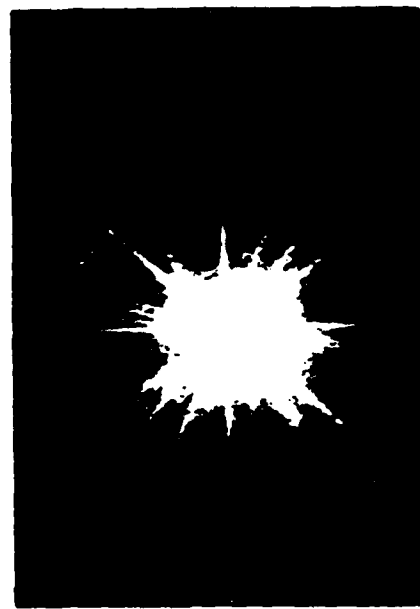
DIFFRACTION PATTERN SAMPLING HYBRID OPTO-ELECTRONIC SYSTEM

- **EFFECTIVE: LASER & SMOOTH INPUT**

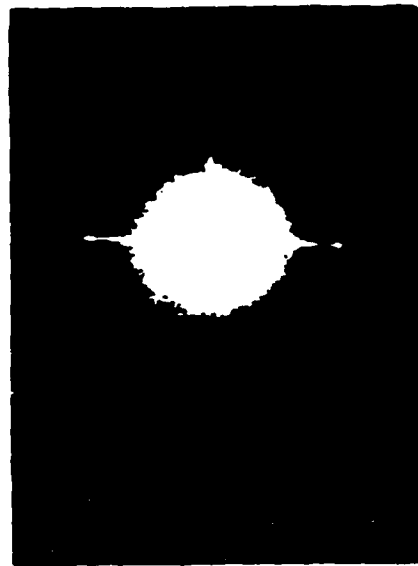


PATTERN RECOGNITION
PARTICULATE ANALYSIS
IMAGE QUALITY
NEEDLE SHARPNESS, ...

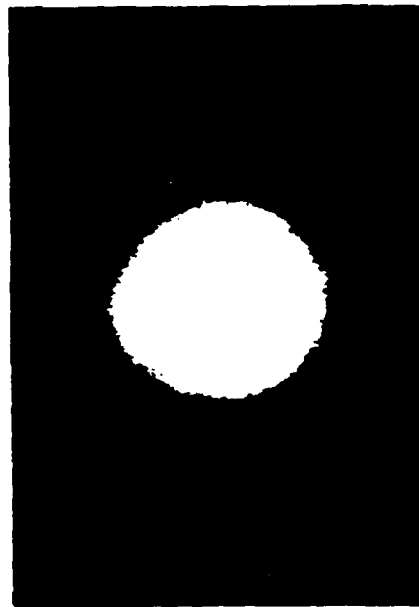
- **INEFFECTIVE: NORMAL ILLUMINATION AND ROUGH OBJECTS**



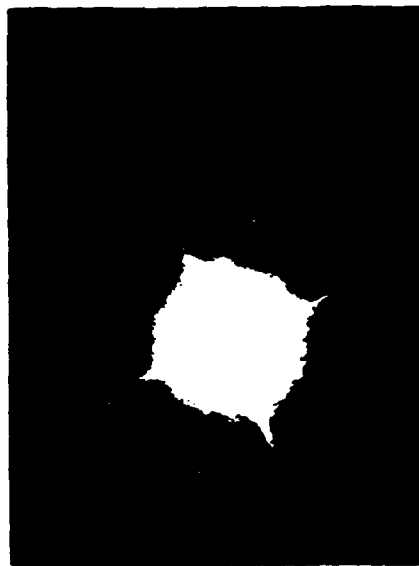
AIRPORT & CITY



PLOWED FIELD



TREES

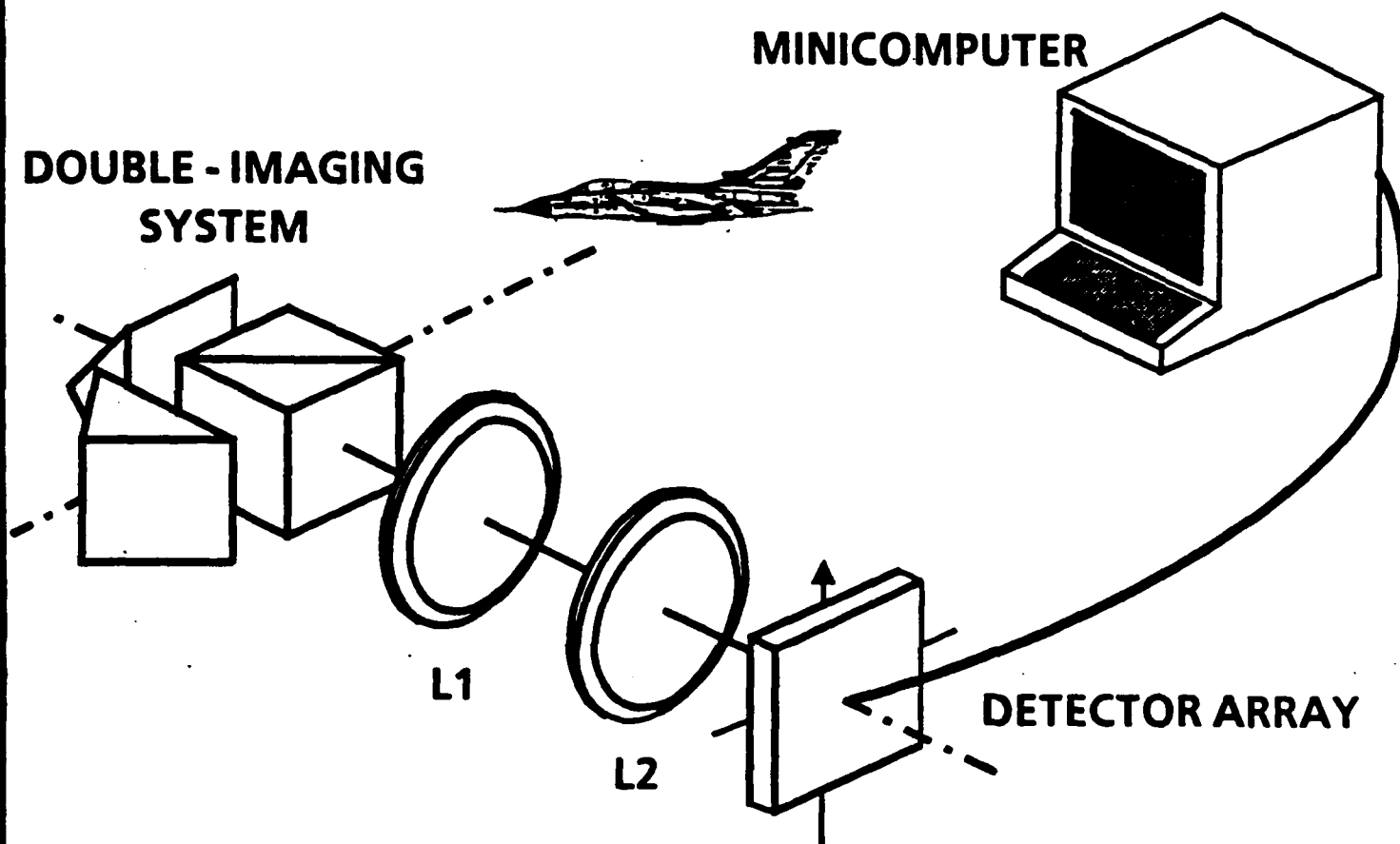


ROAD INTERSECTION

MATCHED FILTERING IN NATURAL ILLUMINATION

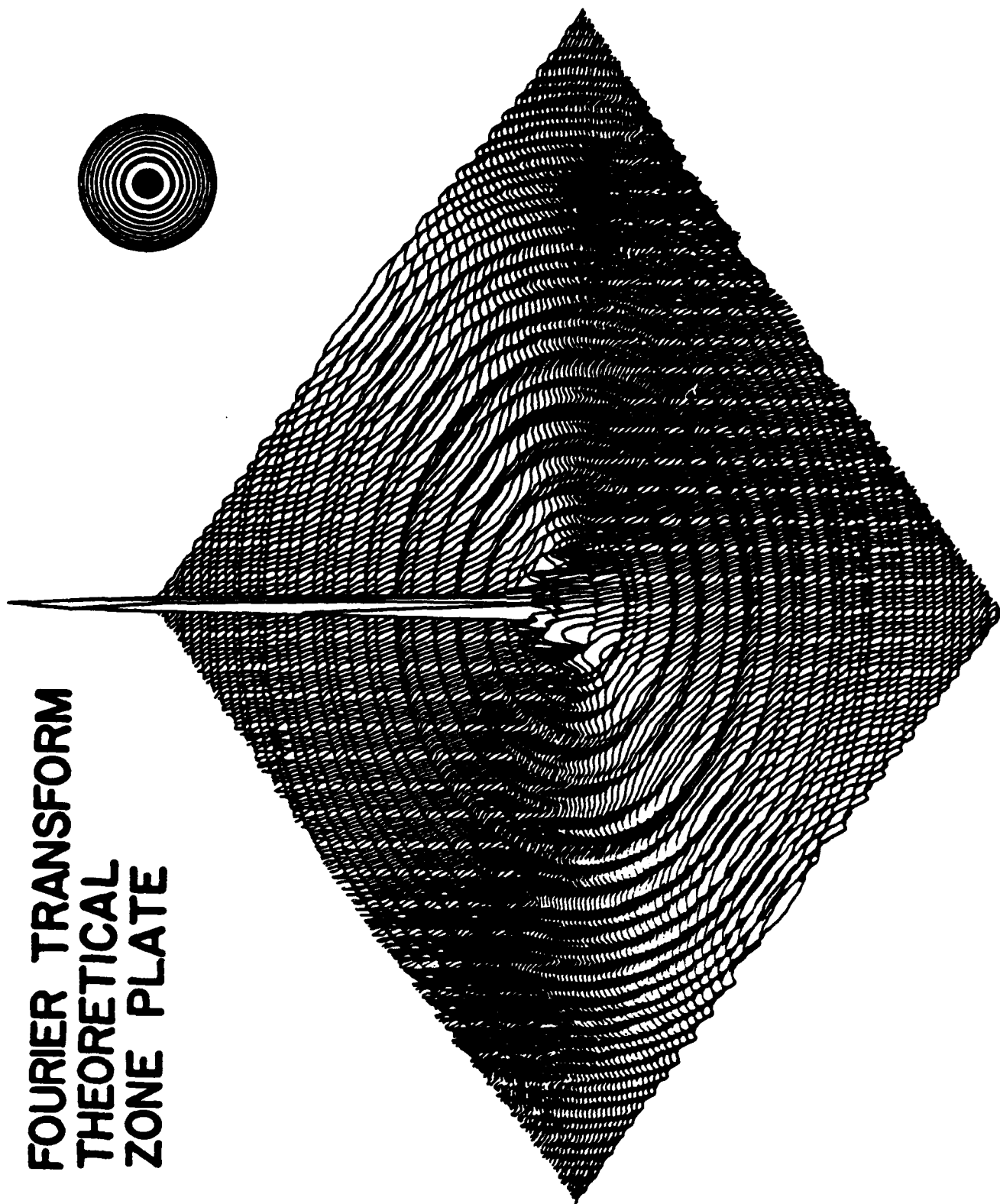
Nicholas George
Shen-ge Wang

● RECENT ACCOMPLISHMENT*

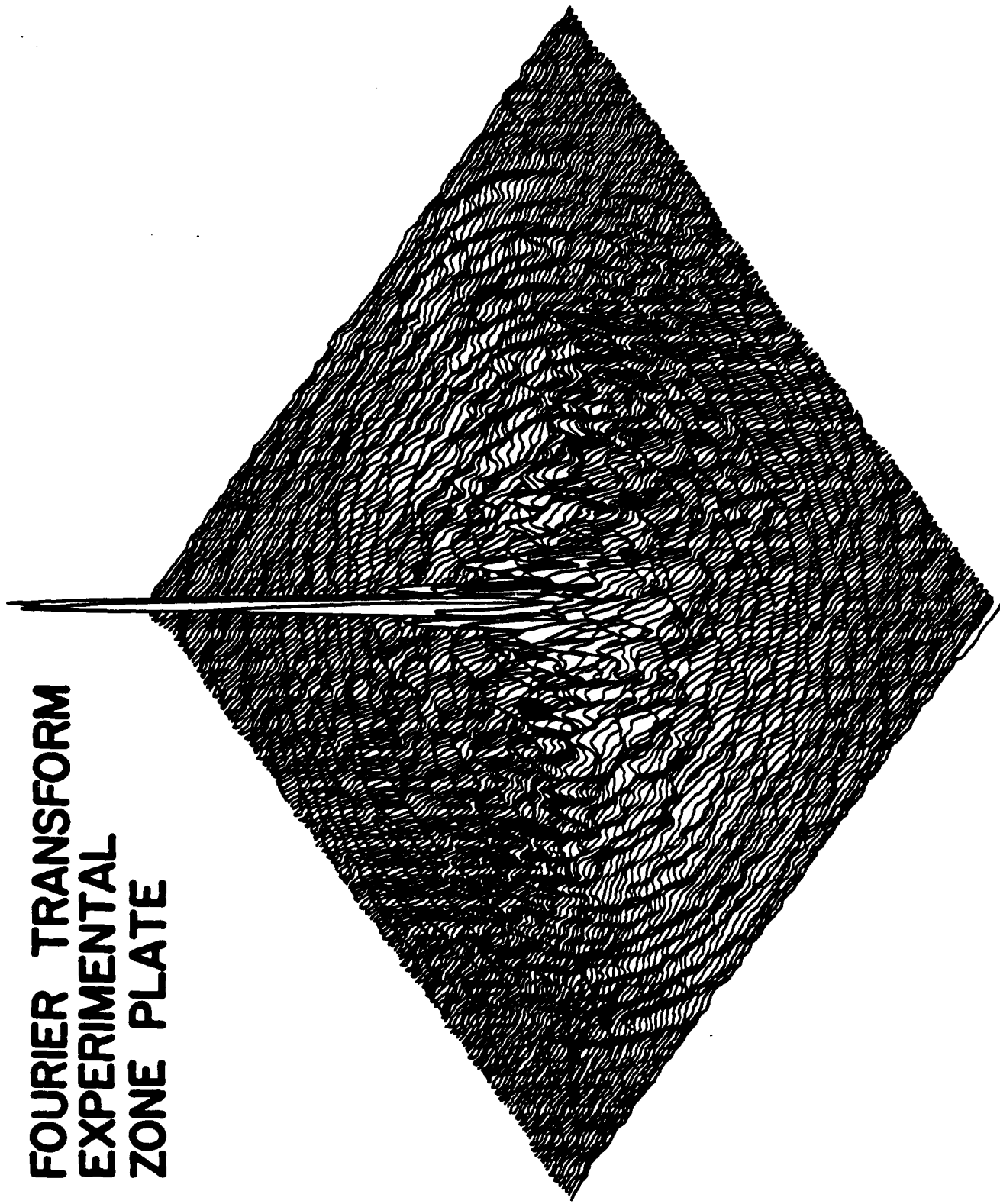


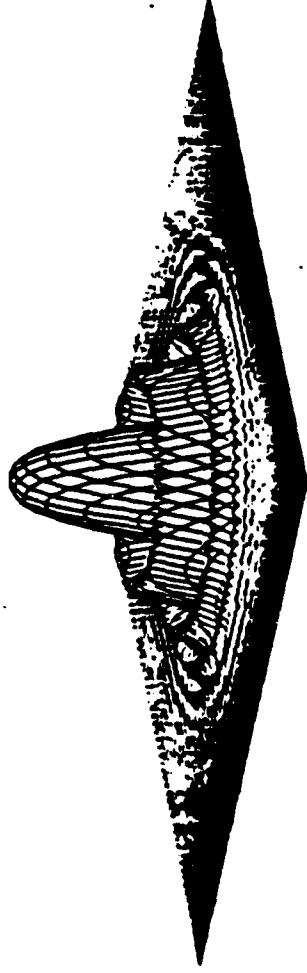
*S. WANG AND N. GEORGE, "CORRELATION AND IMAGE RECONSTRUCTION",
JOSA (A) 2, P. 14 (1985).

**FOURIER TRANSFORM
THEORETICAL
ZONE PLATE**

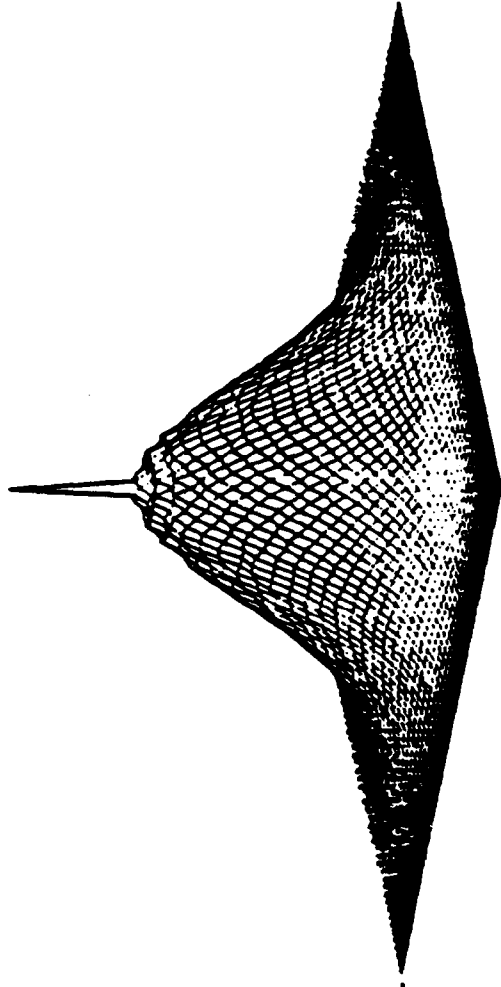


**FOURIER TRANSFORM
EXPERIMENTAL
ZONE PLATE**





9



g★g a/b = 3

INTENSITY CHIRP: $[1 + \cos(2\pi/b^2)(x^2 + y^2)] \exp[-(\pi/a^2)(x^2 + y^2)]$

CORRELATION FUNCTION: THEORY

CORRELATION FUNCTION

REAL VALUED $f(x, y) = f_e(x, y) + f_o(x, y)$

$$R_{ff}(x, y) = \iint_{-\infty}^{+\infty} f(x' + x, y' + y) f(x', y') dx' dy'$$

PROPERTIES:

$$|R_{ff}(x, y)| \leq R_{ff}(0, 0)$$

$$R_{ff}(x, y) = R_{ff}(-x, -y)$$

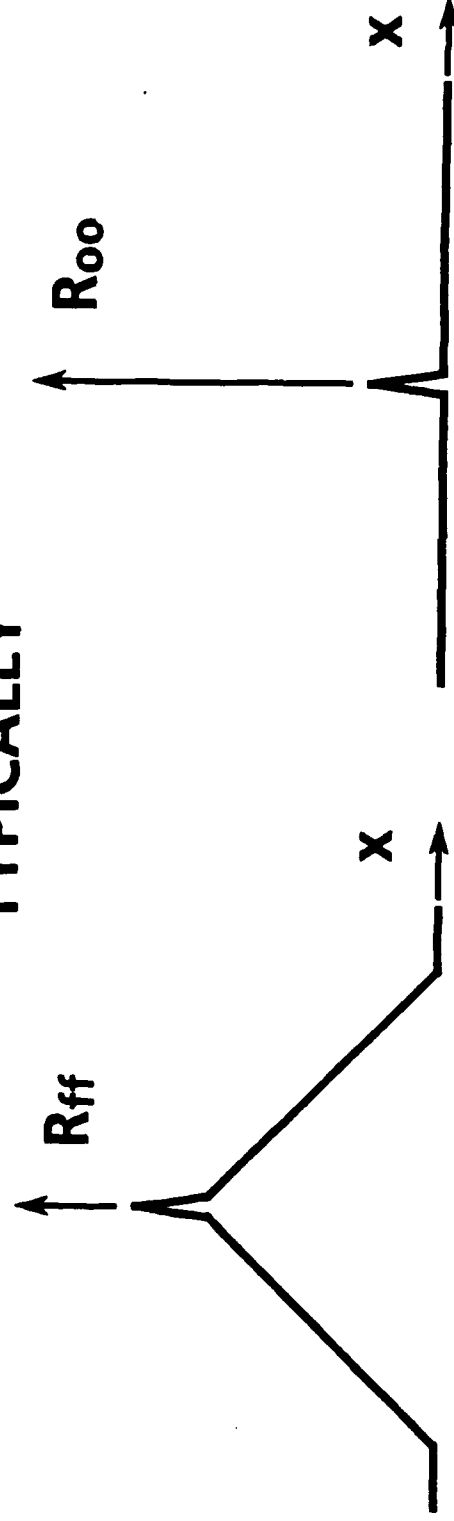
$$R_{ff}(x, y) = R_{ee}(x, y) + R_{oo}(x, y)$$

AUTOCORRELATION

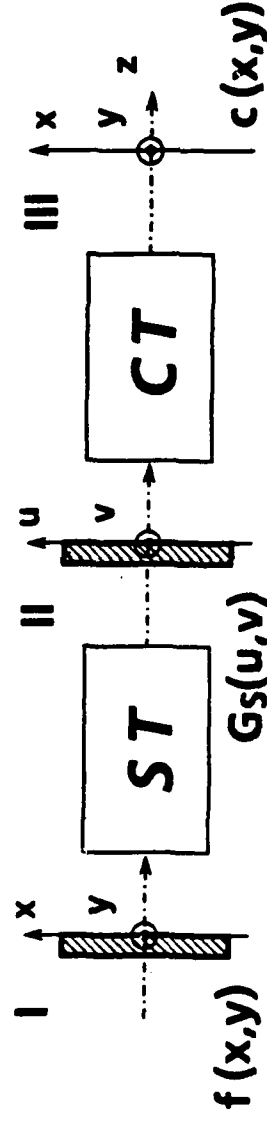
REAL-VALUED FUNCTION, $f(x, y)$

$$R_{ee}(x, y) = \frac{1}{2} R_{ff}(x, y) \pm \frac{1}{4} f(x, y) * [f(x, y) + f(x, y)|_{-x, -y}]$$

TYPICALLY



SINE - COSINE CASCADE CORRELATOR

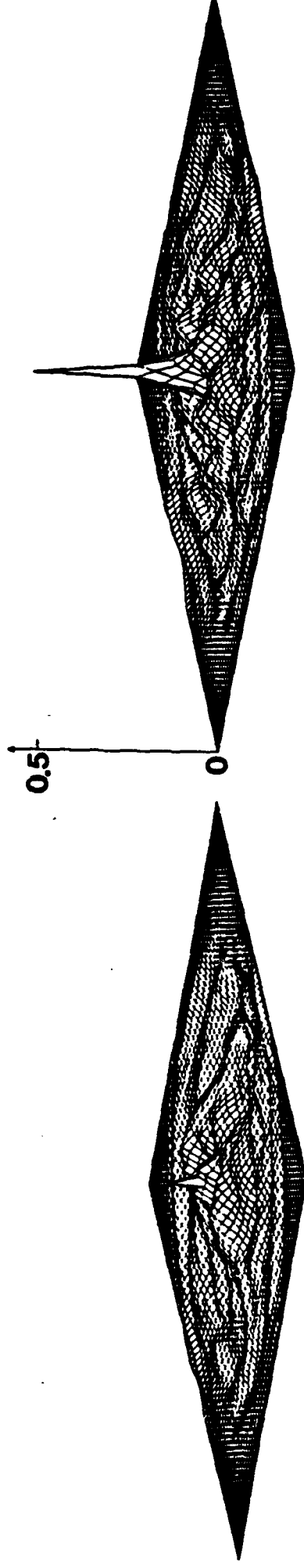


PLANE I TO II:

$$F_s(u, v) = \iint_{-\infty}^{+\infty} f_o(x, y) \sin 2\pi(ux + vy) dx dy$$

OUTPUT III:

$$c(x, y) = \iint_{-\infty}^{+\infty} f_o(x' + x, y' + y) g_o(x', y') dx' dy'$$



\$10 ★ \$1

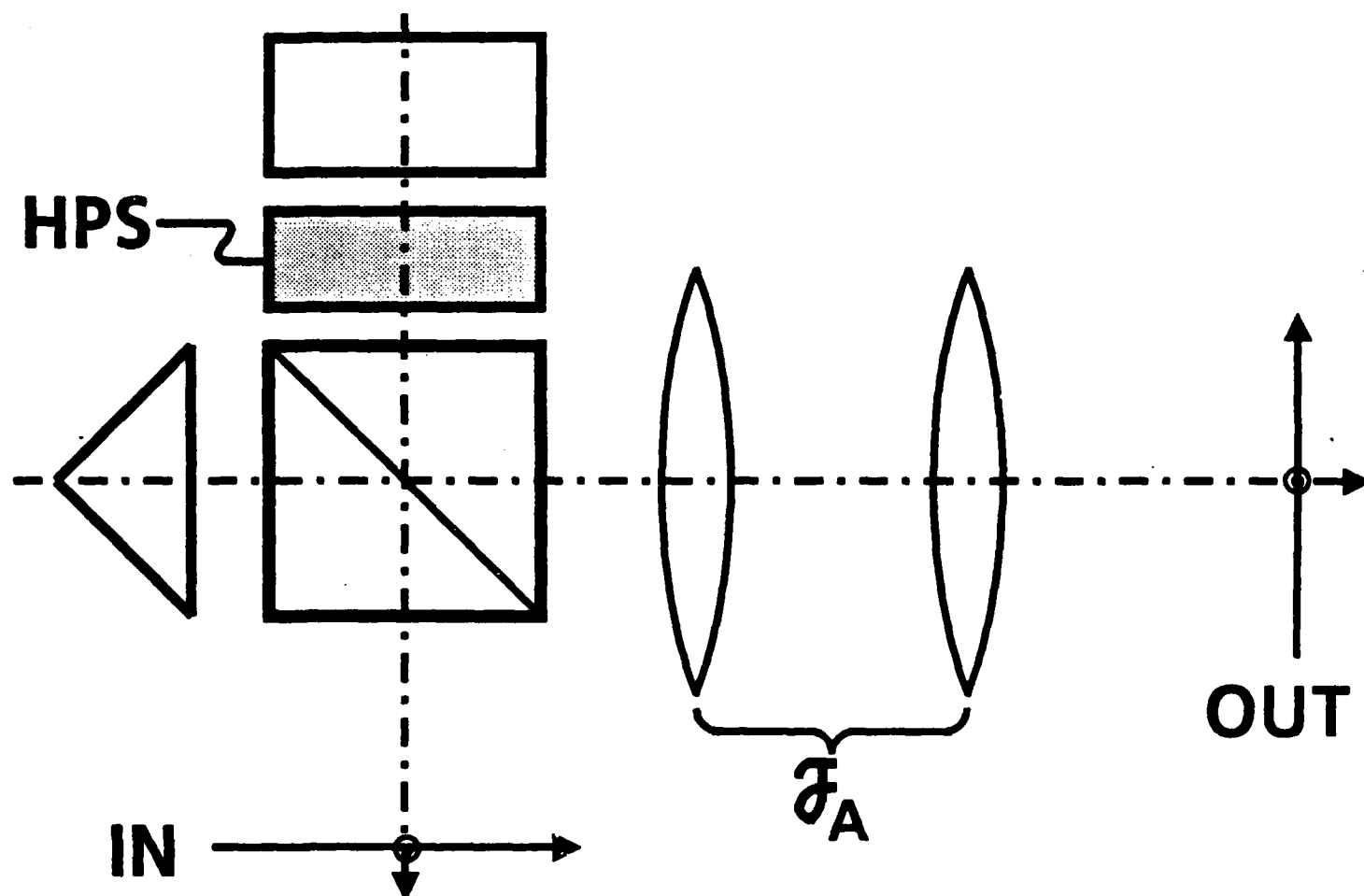
\$1 ★ \$1

**SINE-COSINE CASCADE
COMPUTER SIMULATION (256 x 256 PIXELS)**

OPTICAL TRANSFORMS

SPATIAL SINE OR
COSINE

COMBINING CONCEPTS

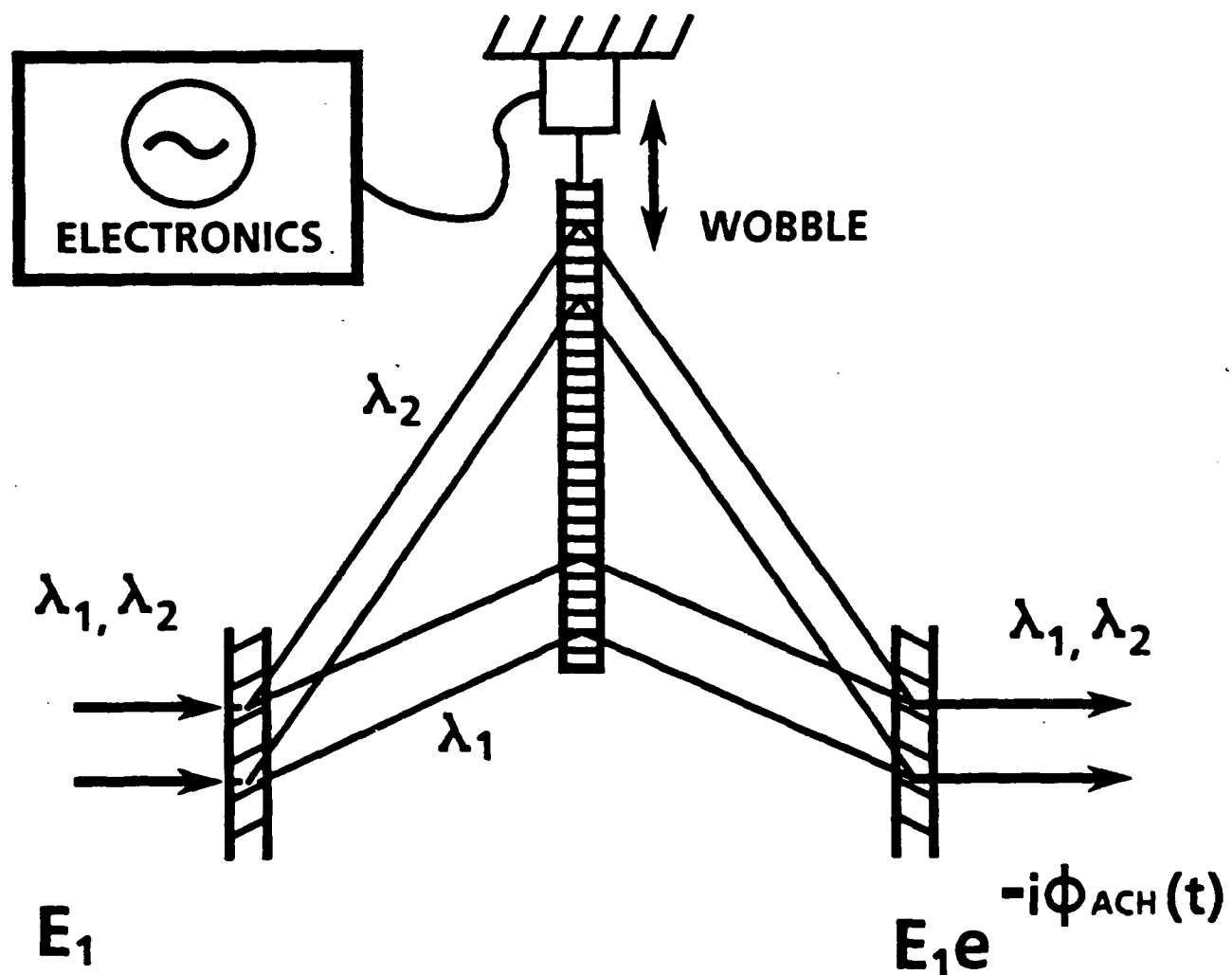


● NOVEL SYSTEM

HOLOGRAPHIC OPTICAL ELEMENTS

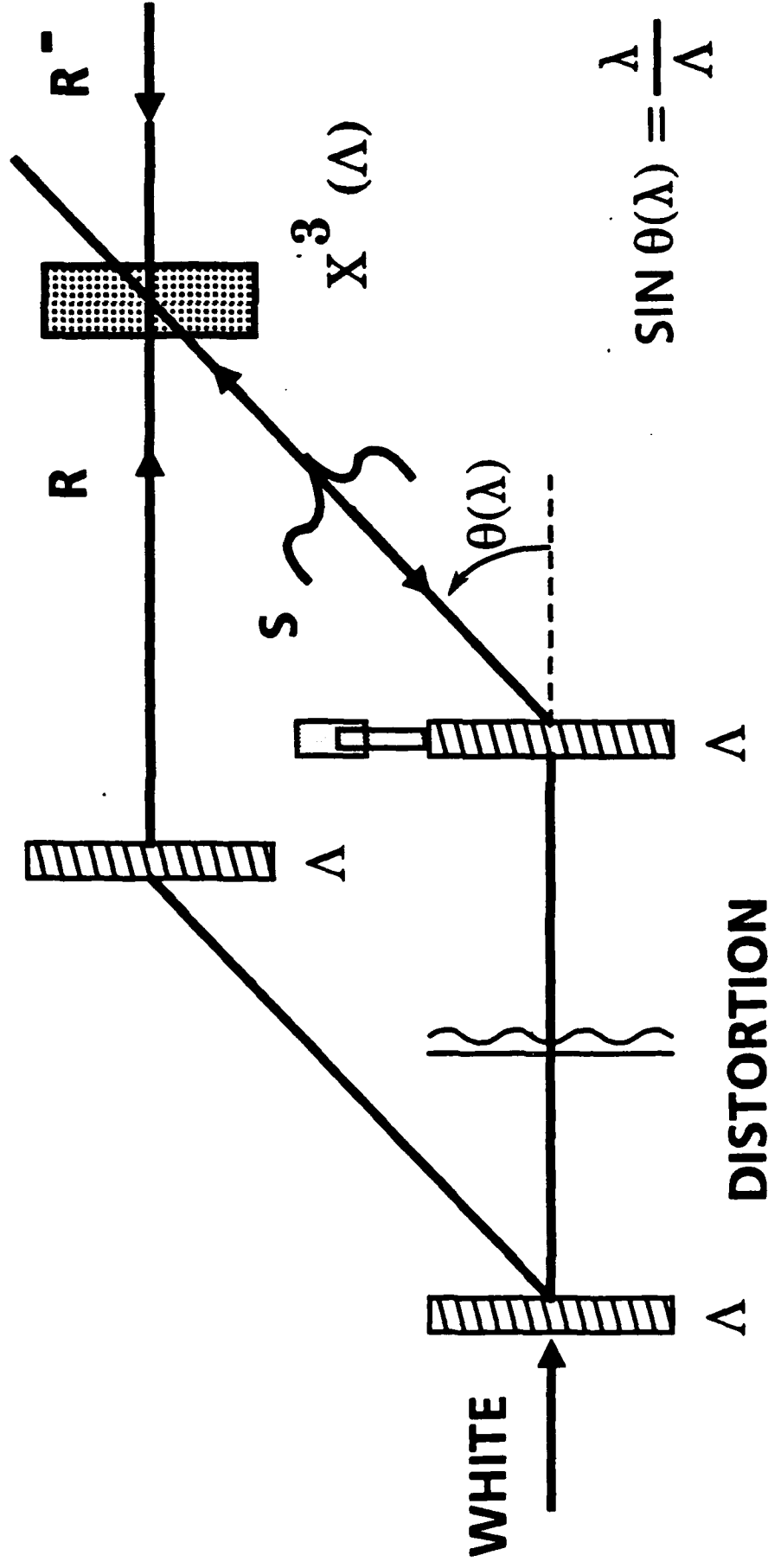
NOVEL CONCEPT (1987)+

BROADBAND ACHROMATIC PHASE SHIFTER

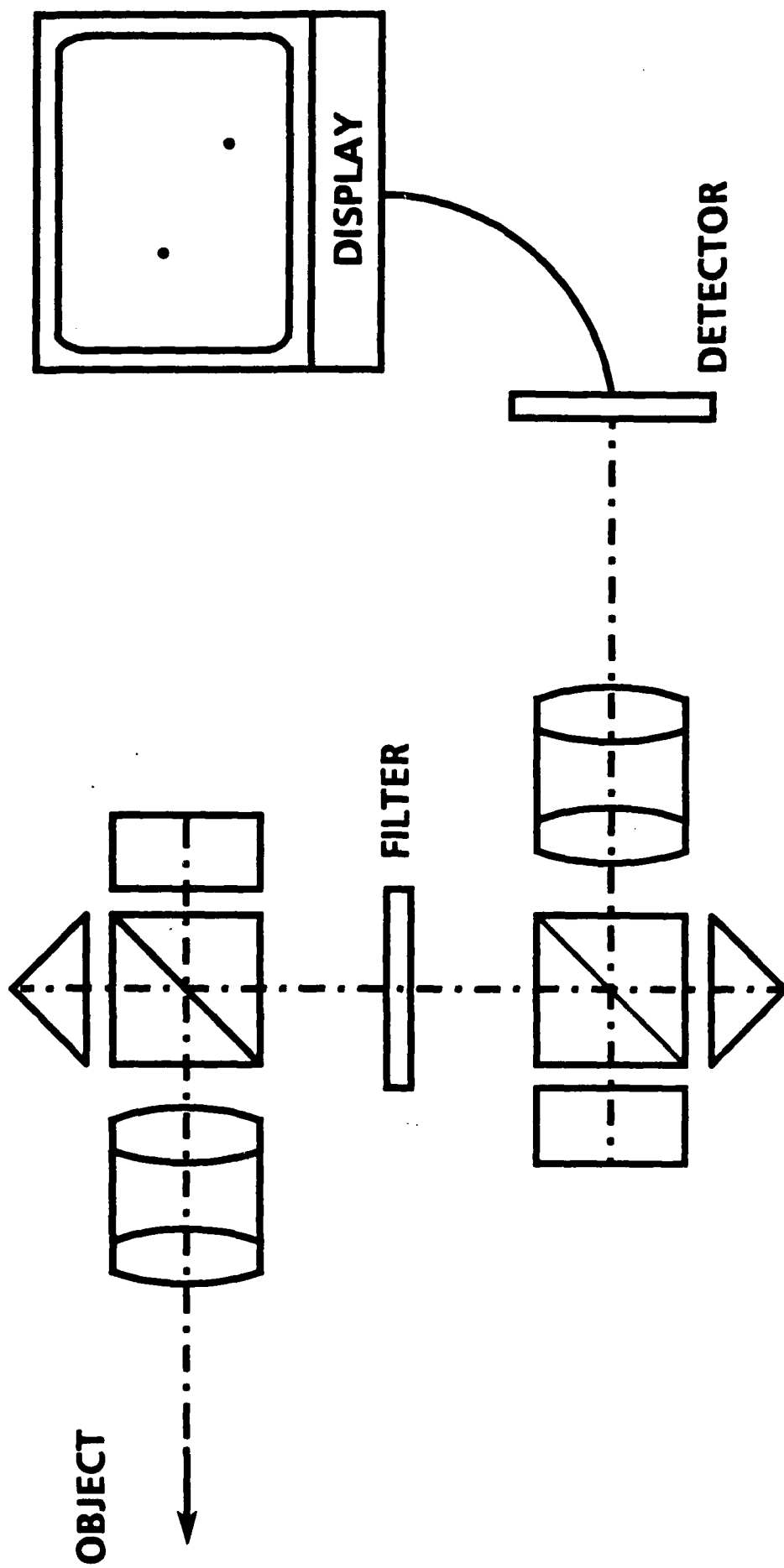


+ Patent Applied For, N. George and T. Stone (1987).

PHASE CONJUGATION WHITE LIGHT



**N. GEORGE
T. STONE
(UNPUBL)**



OPTICAL TRANSFORM & FILTER
(NEXT GENERATION -CONCEPT)

IMAGE SCIENCE

SPATIALLY INCOHERENT ILLUMINATION

MATCHED FILTERING

**ACHROMATIC FOURIER TRANSFORM
LIGHT VALVE**

DIFFRACTION PATTERN SAMPLING

**OPTICAL TRANSFORM -
INTENSITY BASED
LIGHT VALVE**

IMAGE RECOVERY

**NON-LINEAR CRYSTAL
PHASE CONJUGATION -
INTENSITY BASED
DIGITAL TECHNIQUE**

CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
DIFFRACTION PATTERN SAMPLING

AUTOMATIC
PATTERN RECOGNITION
AND
DIFFRACTION PATTERN
SAMPLING

The Institute of Optics
The University of Rochester

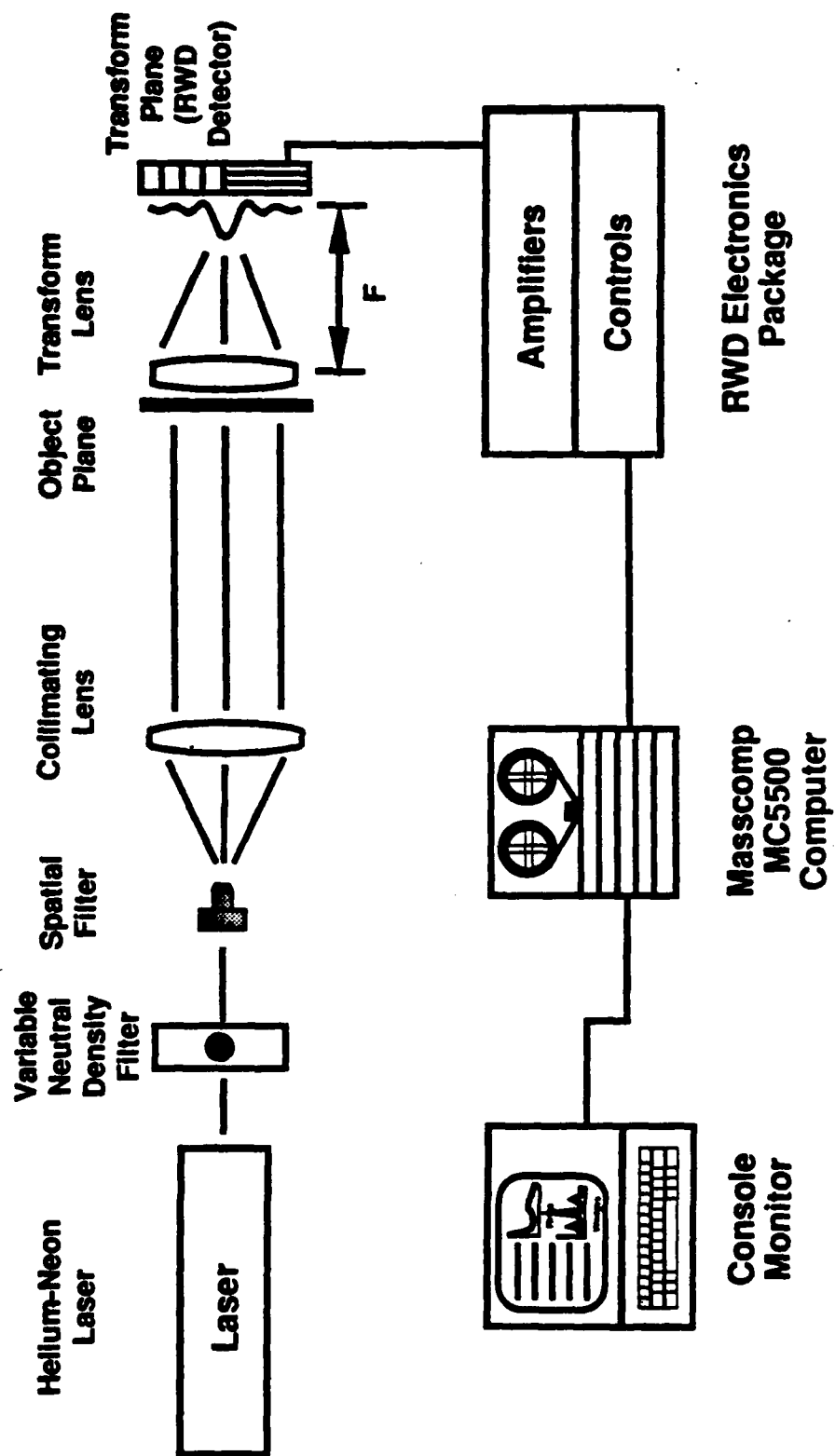
Diffraction Pattern Sampling

Used for: *

- AERIAL
- CATS/DOGS
- PHOTOMICROGRAPHS
- HYPODERMIC NEEDLES
- HANDWRITING
- PLASTIC FILM
- IMAGE QUALITY
- LENS QUALITY

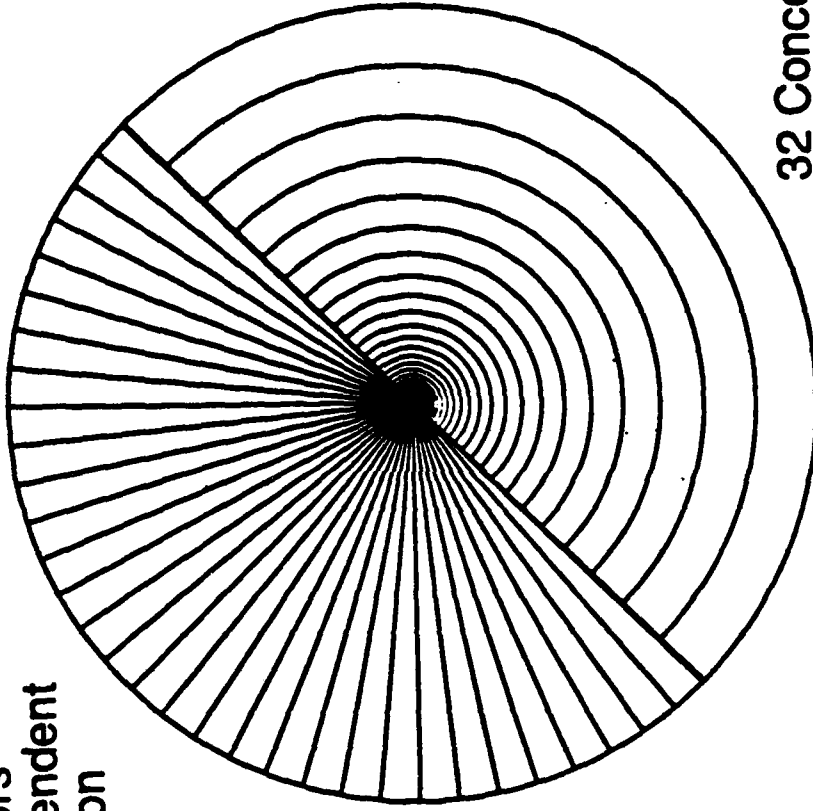
* George, Nicholas, *Automatic Pattern Recognition*, The Institute of Optics Summer School Notes, 1984

Hybrid-Optic Diffraction Pattern Sampling System



Ring-Wedge Detector *

32 Wedge Detectors
Measuring Angle-Dependent
Spectral Information



32 Concentric Ring Detectors
Measuring Angle-Independent
Spectral Information

• Permission ARC, Inc.
US Patent No. 3,689,772

Analysis of Aerial Photography *

Examples:

- Cloud cover detection
- Detection of anomalies in ocean wave patterns



Fig. 5. Sampling grid for cloud test set.



Fig. 6. Results of cloud detection experiment.

Cloud cover detection



Fig. 7. Sampling apertures for wave patterns.

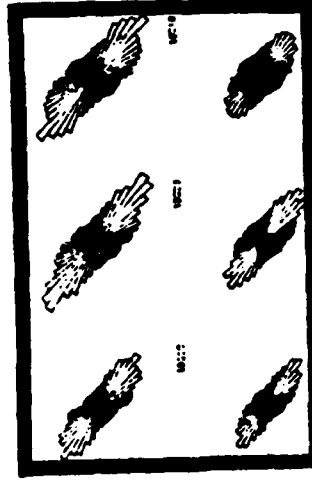


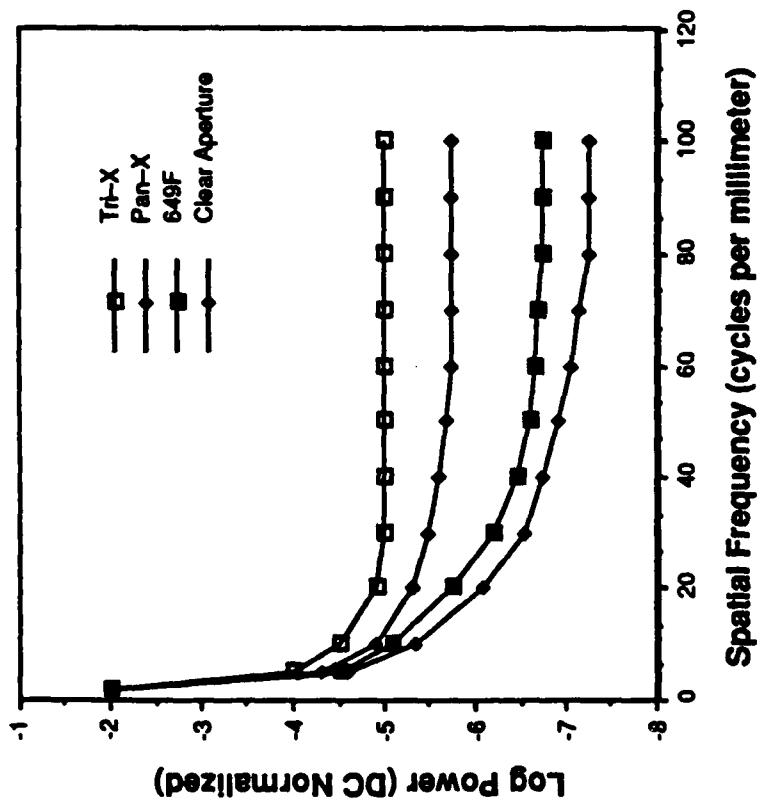
Fig. 8. Rose diagram of wedge data.

Ocean wave monitoring

- * George Lukes, "Rapid Screening of Aerial Photography by OPS Analysis", SPIE vol. 117, 89 (1977).

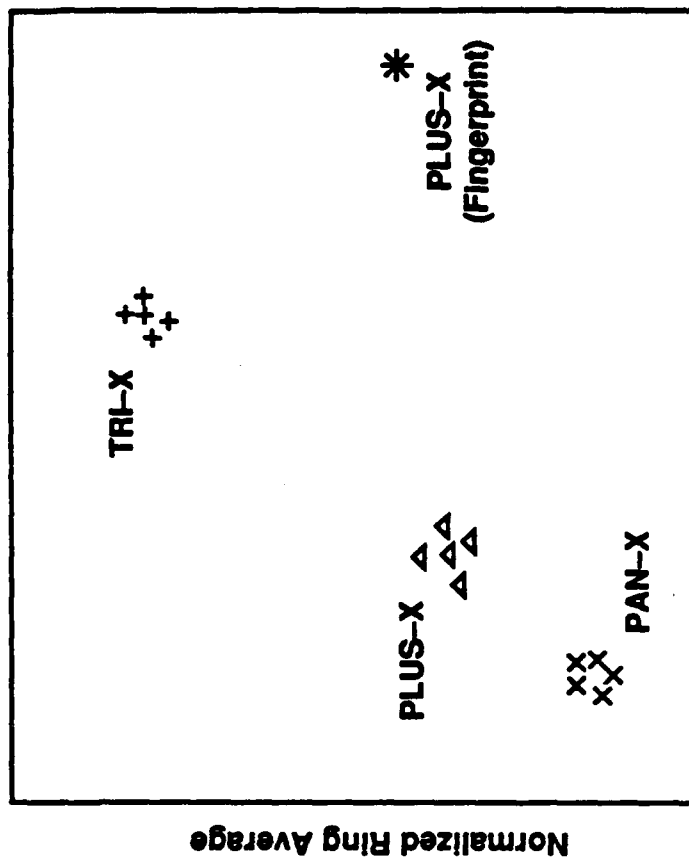
Film Grain Spectra using Coherent Optical Methods *

* From Armstrong and Thompson, "Comparison of Coherent and Incoherent Optical Spectral Analysis Techniques in Image Evaluation", SPIE vol. 117, pp. 57-66.



Scatterplot indicating tight clustering of film samples. Simple linear discriminants result in very fast recognition (<3 ms).

Notice the easily detectable fingerprint defect.

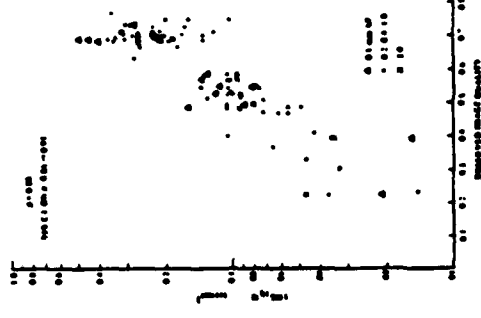


Second Moment of the Power Spectrum

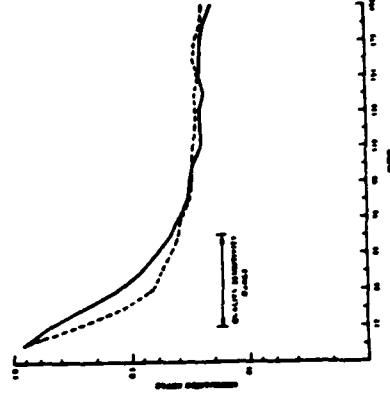
IMAGE QUALITY *

$$M = \frac{\int_0^\infty v^3 P(v) dv}{\int_0^\infty v P(v) dv} = \frac{\int_0^\infty v^3 H(v) dv}{\int_0^\infty v H(v) dv}$$

Second Moment of the Power Spectra



M vrs. Subjective Image Quality



Sensitivity range for Image Quality Measurement

- A low order moment of the coherent power spectra can be useful for image quality evaluation.
- Obtained quantitative results indicating correlation between a low order merit function and subjective image quality measurement.
- There exists a sensitivity range in the optical power spectrum for measuring image quality.
- Aperture effects can be removed from the power spectra for the second moment of the power spectra.

* Norman Noll, "Scene power spectra: the moment as an image quality factor", App. Opt., vol. 15, no. 11, 2846 (1976).

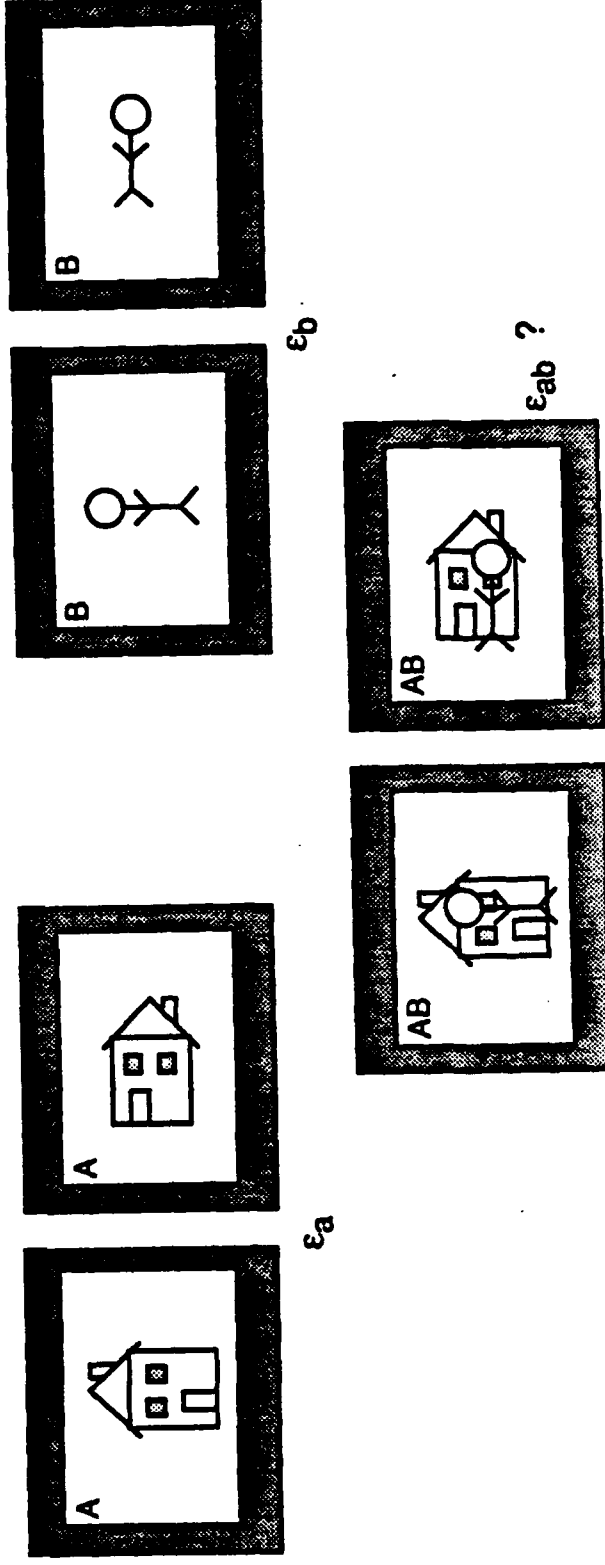
Image Quality

- Predict how defocus in the image affects the optical transform as sampled by the Ring-Wedge Detector
- Can a feature be developed that will optimally determine defocus independent of image content?
- Specific problem:
 - ◆ Pick one feature: 2nd Moment of the Power Spectrum
 - ◆ Analytically predict how defocus affects this feature
 - ◆ Determine defocus from RWD scans of imagery
 - Can aperture effects be removed?
 - Can grain effects be accounted for?
 - Can feature be made image-content independent?
 - ▶ Single image - Single image class
 - ▶ Single image - Many image classes

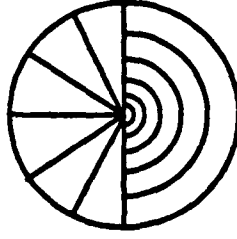
Consider a 2-class sorting problem

- Feature F_a sorts objects A into class 1 and class 2 with a recognition accuracy of ϵ_a .
- Feature F_b sorts objects B into class 1 and class 2 with a recognition accuracy of ϵ_b .

Consider an image consisting of both objects A and B. Using only features F_a and F_b , with what recognition accuracy ϵ_{ab} can the image be sorted into classes 1 or 2?



Pooled Wedge Difference Sum Algorithm



Wedge #	Sample Wedges	Class 1 Pooled Wedges	Differences (Absolute Value)	Class 2 Pooled Wedges	Differences (Absolute Value)
1	129	133	4	126	3
2	237	252	15	133	104
3	153	140	13	139	14
4	149	137	12	140	9
5	156	139	16	230	74
6	129	135	+ 6	135	+ 6
PWDS = $\log(S_1/S_2) = -1.574$		S₁: 66		S₂: 210	

Pooled Wedge Difference Sum Algorithm

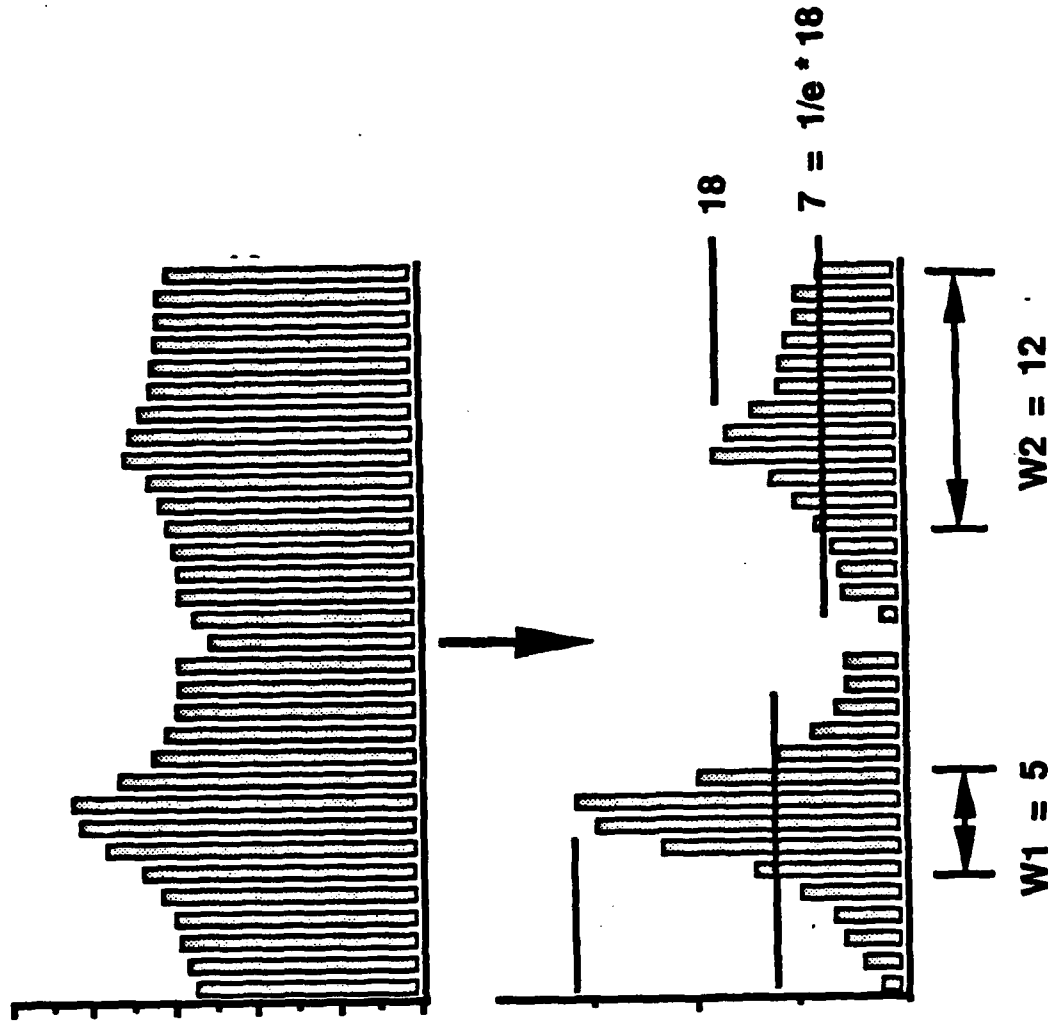
The pooled wedge difference sum algorithm is demonstrated above. The PWDS is calculated for a sample against the pooled (average) vectors for classes 1 and 2. Low feature values correspond to a high degree of similarity. In the above example, the sample most nearly matches class 1 as PWDS value of 66 is significantly less than 210.

Spike Width Feature Algorithm

- Subtract background
- Find spike maxima
- Determine width of the spike at the $1/e$ point
- Add widths of all spikes

$$12 = 1/e \cdot 32$$

$$\text{SpW} = W1 + W2 = 17$$



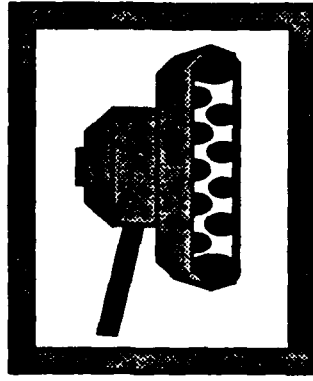
Example of the Spike Width (SpW) feature algorithm.

Orientation Sorting Results:

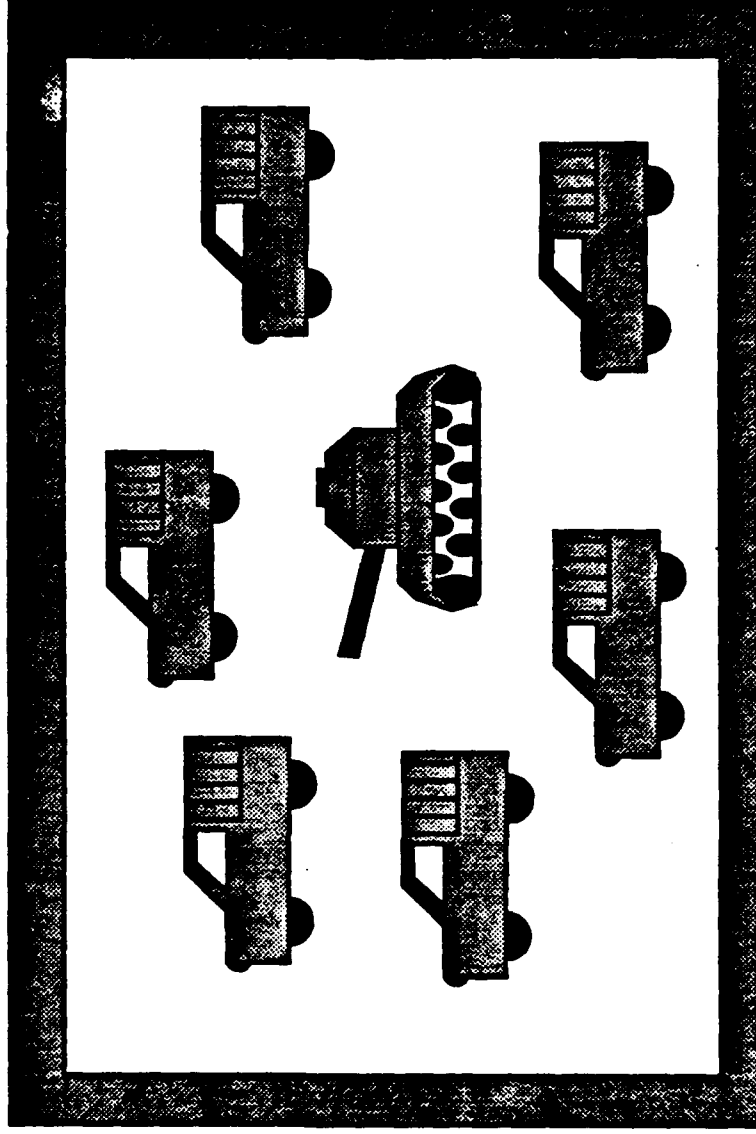
Data Set		House	People	Average	Set Average	Global Average
Learning Set	Landscape	21.2%	4.3%	12.8%	10.95%	13.68%
	Portrait	18.2%	.0	9.1%		
Test Set	Landscape	20.3%	8.3%	14.2%	16.4%	
	Portrait	7.8%	29.2%	18.5%		

Consider

A given object produces a signature pattern in the optical transform that is recognizable with accuracy ϵ . How does the presence of other, potentially recognizable, objects in the image affect the recognition accuracy?



Recognized with accuracy ϵ

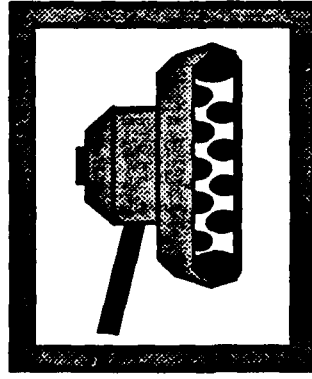


$\epsilon ?$

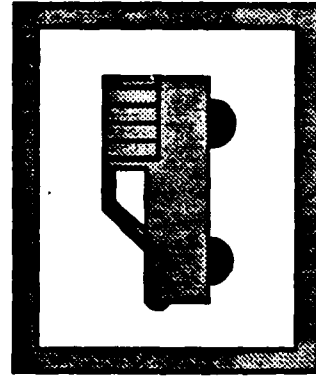
Consider

- Object A can be recognized with an accuracy of ϵ_a using feature F_a
- Object B can be recognized with an accuracy of ϵ_b using feature F_b

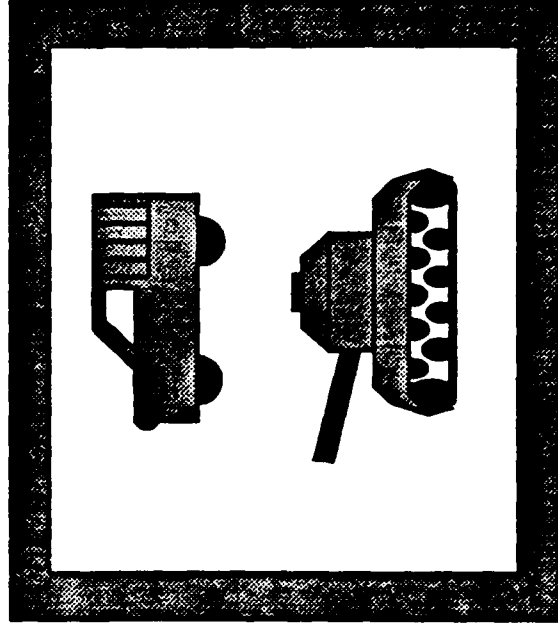
With what accuracy can both objects A and B in the same image be recognized?



Recognized with accuracy ϵ_a



Recognized with accuracy ϵ_b



$\epsilon ?$

Incoherent Diffraction Pattern Sampling

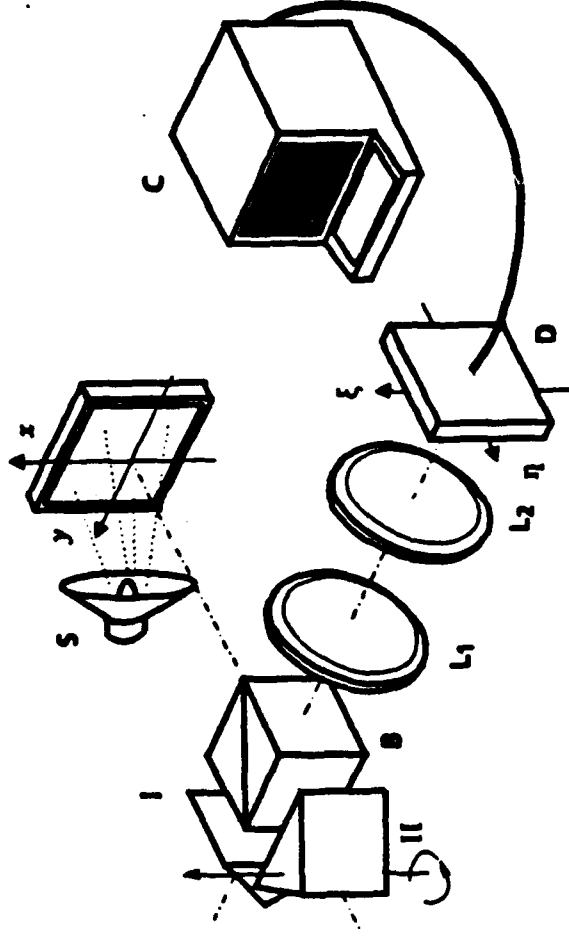
Why?

- Coherent illumination requirements limit the useful applications of DPS to objects that are very smooth (on a microscopic scale) or to objects with strong specular reflections. Incoherent optical transform technology removes these limitations and allows DPS to be used in virtually unlimited applications.

- Incoherent illumination is a lot cheaper!

How?

- Incoherent-to-Coherent conversion
(LCLV, PROM, etc.)
- Real-time holography
- Incoherent optical transforms *



Optoelectronic hybrid for
cosinusoidal transforms of rough
objects illuminated by white light

* Shen-ge Wang, *Optical Transforms in White Light*, Ph.D. Thesis, University of Rochester, 1986.

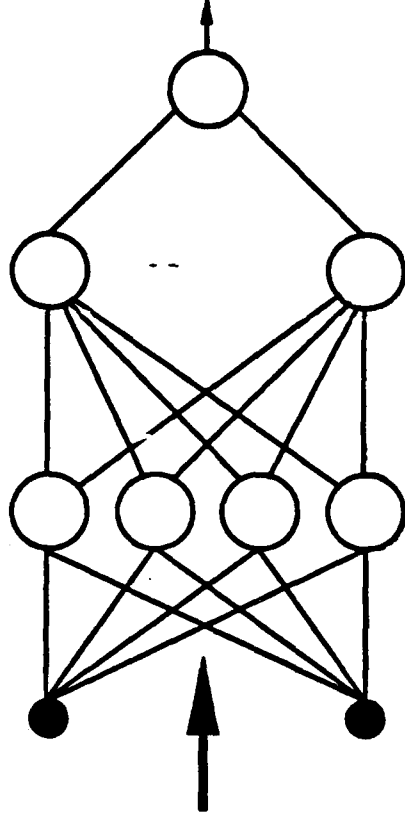
Neural Networks and Diffraction Pattern Sampling

Neural networks are:

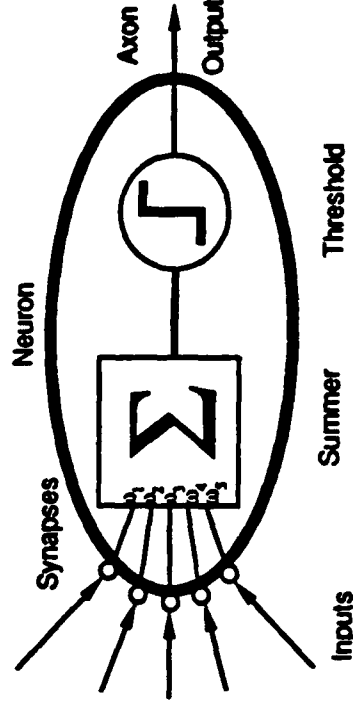
- very fast (once trained)
- can be reprogrammed for different functions
- are not limited to simple linear or piecewise-linear discriminants

Why couple neural networks to diffraction pattern sampling?

- increase recognition speed significantly
- since RWD reduces data to 64 pixels, current neural network hardware can be used to construct a network capable of complicated discrimination



3-Layer Perceptron Neural Network



Neuron Model

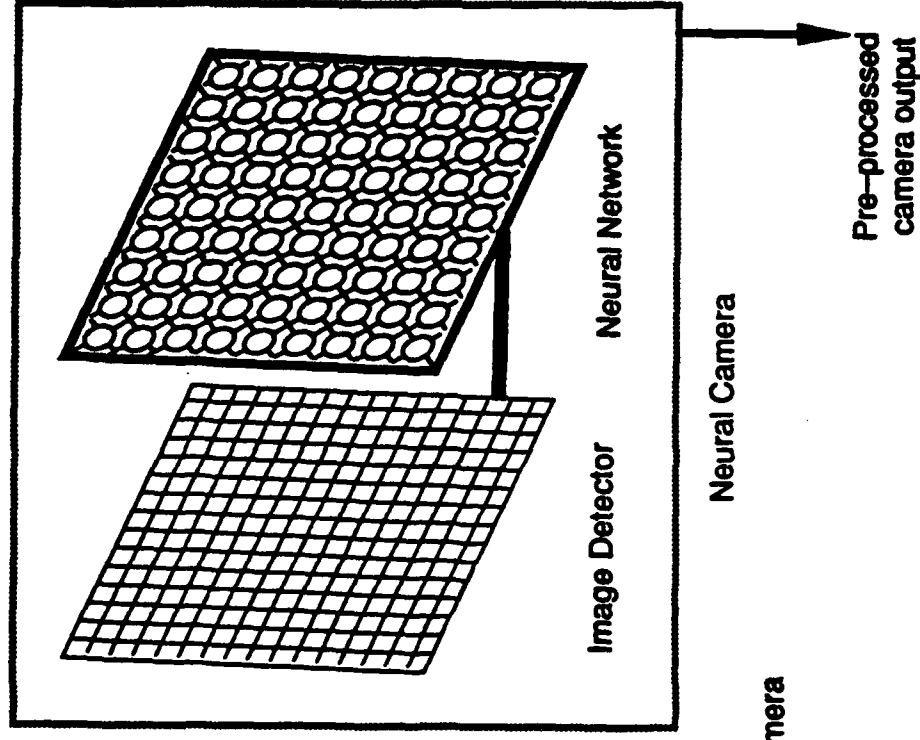
The Neural Camera

What is a neural camera?

- low-to-medium resolution image detector (ccd, vidicon, etc.)
- rectangular layout of detector elements (256x256)
- Digitized detector outputs feed into a fully interconnected neural network.

Why build a neural camera? – Configurable pre-processing within the camera

- generate a variety of transforms within the camera by adjusting the operation of the network
- perform pattern recognition, segmentation, etc. within the camera as a preprocessing function.



CENTER FOR OPTO-ELECTRONIC SYSTEMS RESEARCH
IMAGE RETRIEVAL

Image Recovery

Rob Rolleston

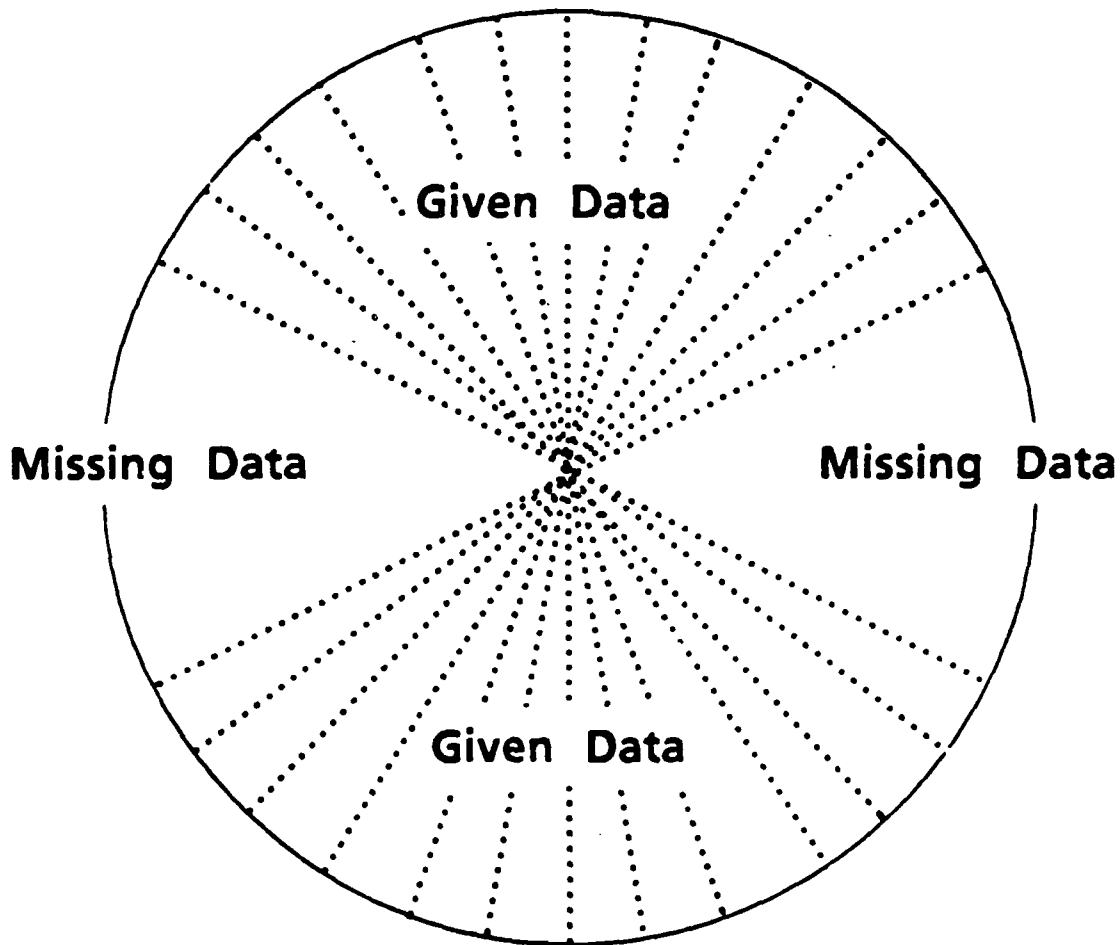
**The Institute of Optics
University of Rochester**

Image Recovery

Given only partial information about an image and the transform, Is it possible to recover (or reconstruct) the unknown image ?

Computer Aided Tomography:

Given the Fourier spectrum only in a wedge shaped region, it is possible to fill in the missing portion of the spectrum and thus recover the unknown image.



History

1892 A. A. Michelson and Lord Raliegh

- visibility fringes

1965 Walther; Wolf

- analytic properties of functions

1974 Napier and Bates

- 2-D Polynomials

1971 Gerchberg and Saxton

- iterate between two planes

1982 Youla and Webb

- convex projections

Fourier Transform

$$G(f_x, f_y) = \iint g(x, y) \exp\{-i2\pi(xf_x + yf_y)\} dx dy$$

$$g(x, y) = \iint G(f_x, f_y) \exp\{+i2\pi(xf_x + yf_y)\} df_x df_y$$

Polar Form

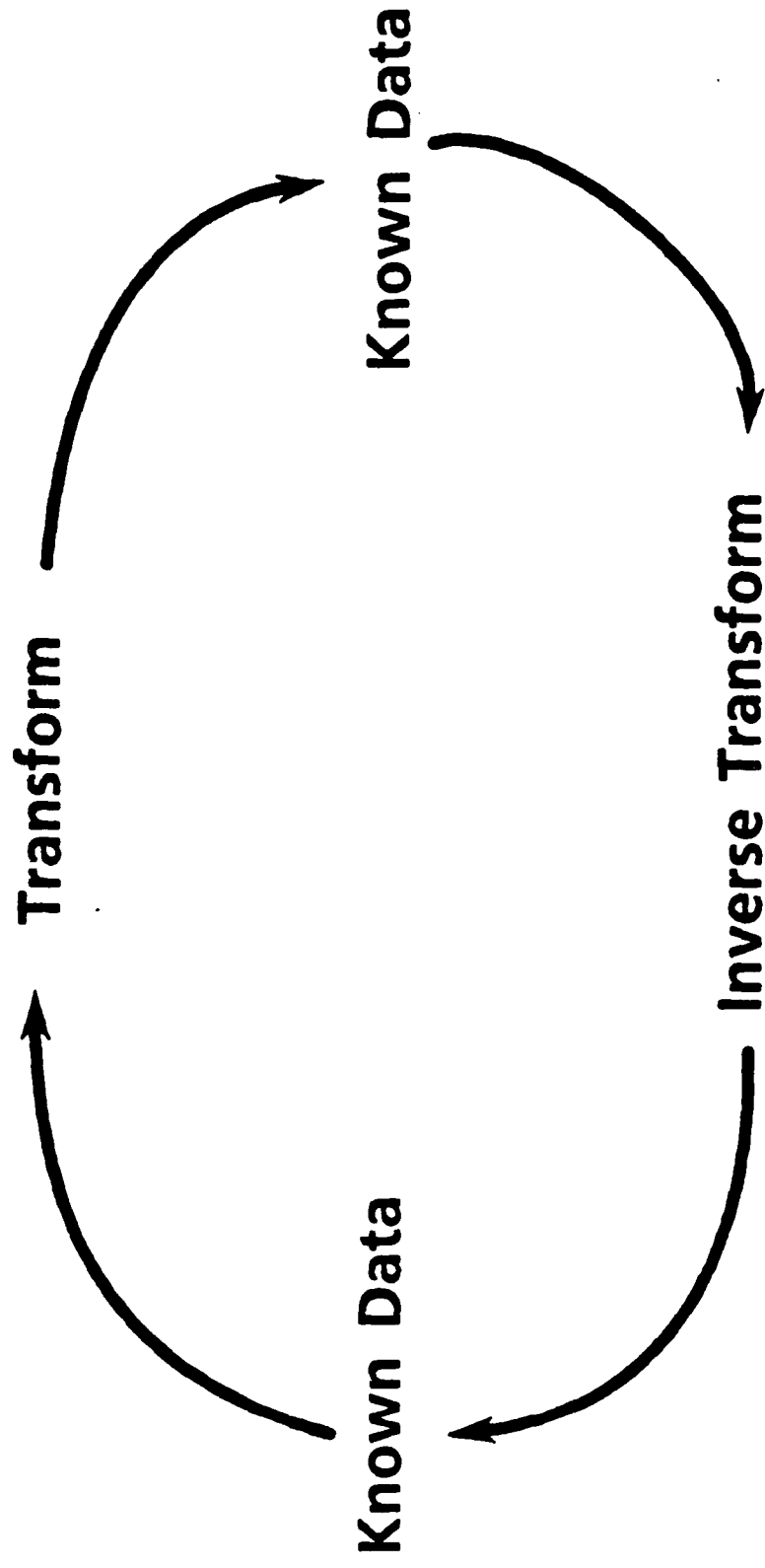
$$\text{Magnitude: } |G(f_x, f_y)| = [G(f_x, f_y)G^*(f_x, f_y)]^{\frac{1}{2}}$$

Phase:

$$\cos[\Phi(f_x, f_y)] = \frac{\text{RE}[G(f_x, f_y)]}{|G(f_x, f_y)|}$$

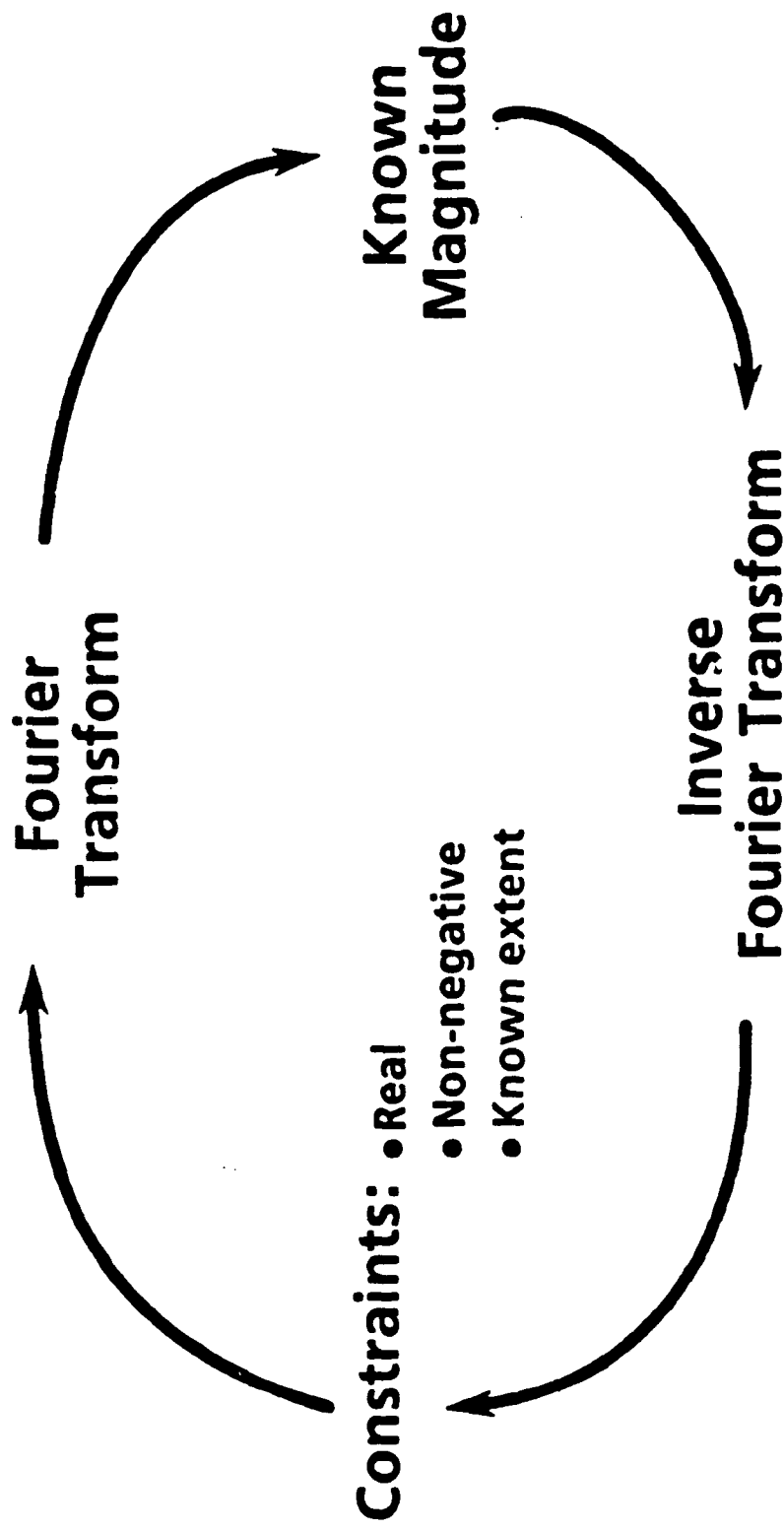
$$\sin[\Phi(f_x, f_y)] = \frac{\text{IM}[G(f_x, f_y)]}{|G(f_x, f_y)|}$$

Gerchberg-Saxton Algorithm



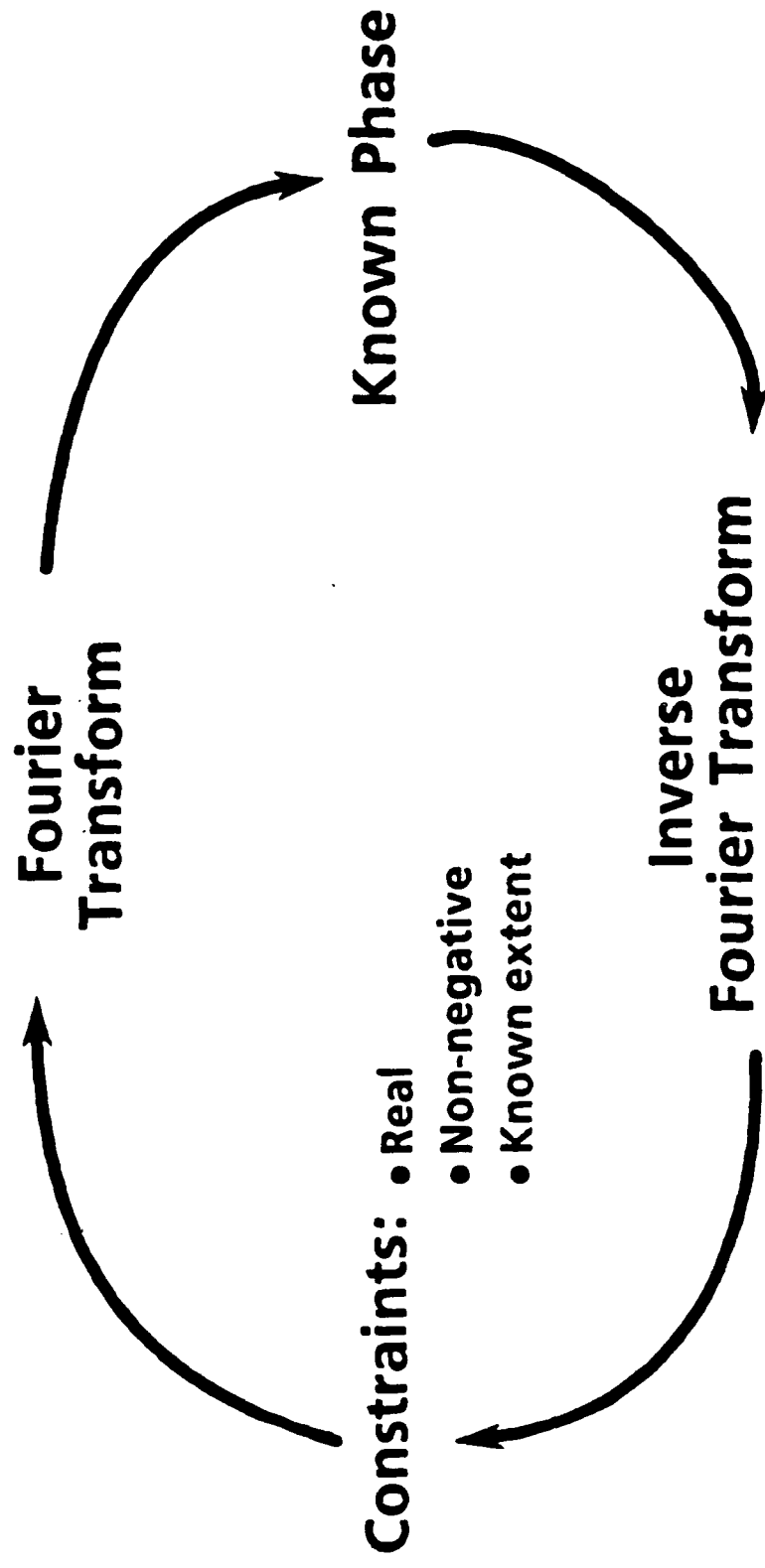
Phase Retrieval

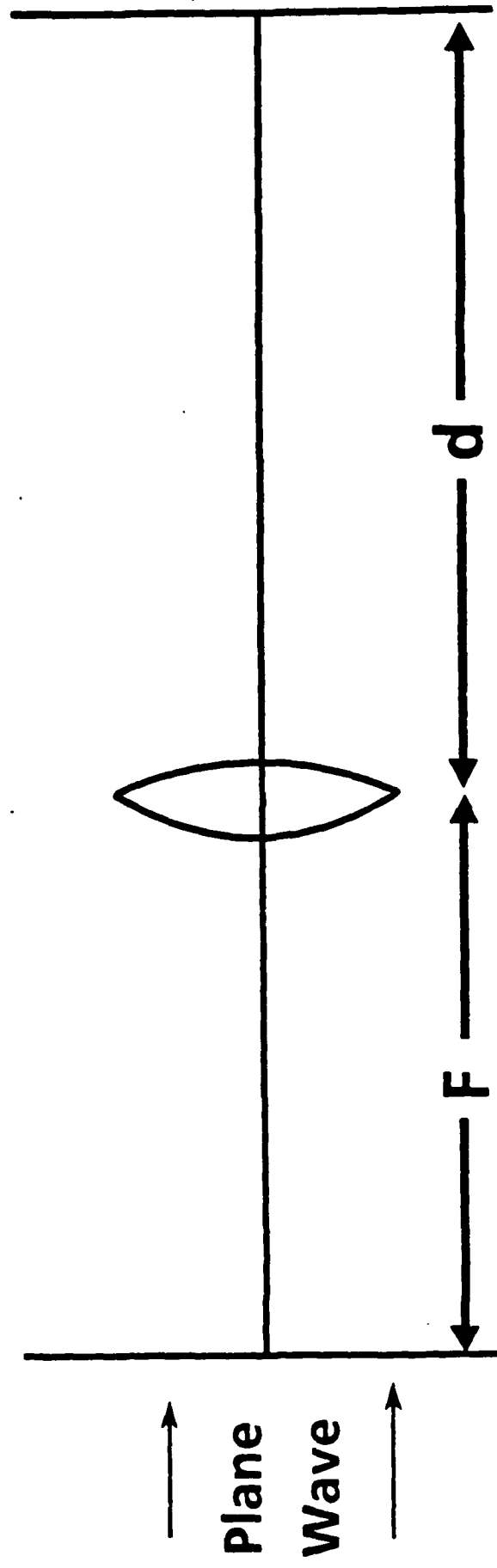
(Fienup, 1978)



Magnitude Retrieval

(Oppenheim, Lim, Hayes, 1981)





$d = F$: Fourier Transform

$d \neq F$: Fresnel Zone Transform

FRESNEL-ZONE TRANSFORM PAIR

$$G(f_x, f_y) = \iint g(x, y) K(x, y; f_x, f_y) dx dy$$

$$g(x, y) = \iint G(f_x, f_y) K^*(x, y; f_x, f_y) df_x df_y$$

Transform Kernel

$$K(x, y; f_x, f_y) = \exp\{-i\pi\alpha_1(x^2 + y^2) - i2\pi(f_x x + f_y y)\}$$

Offset parameter

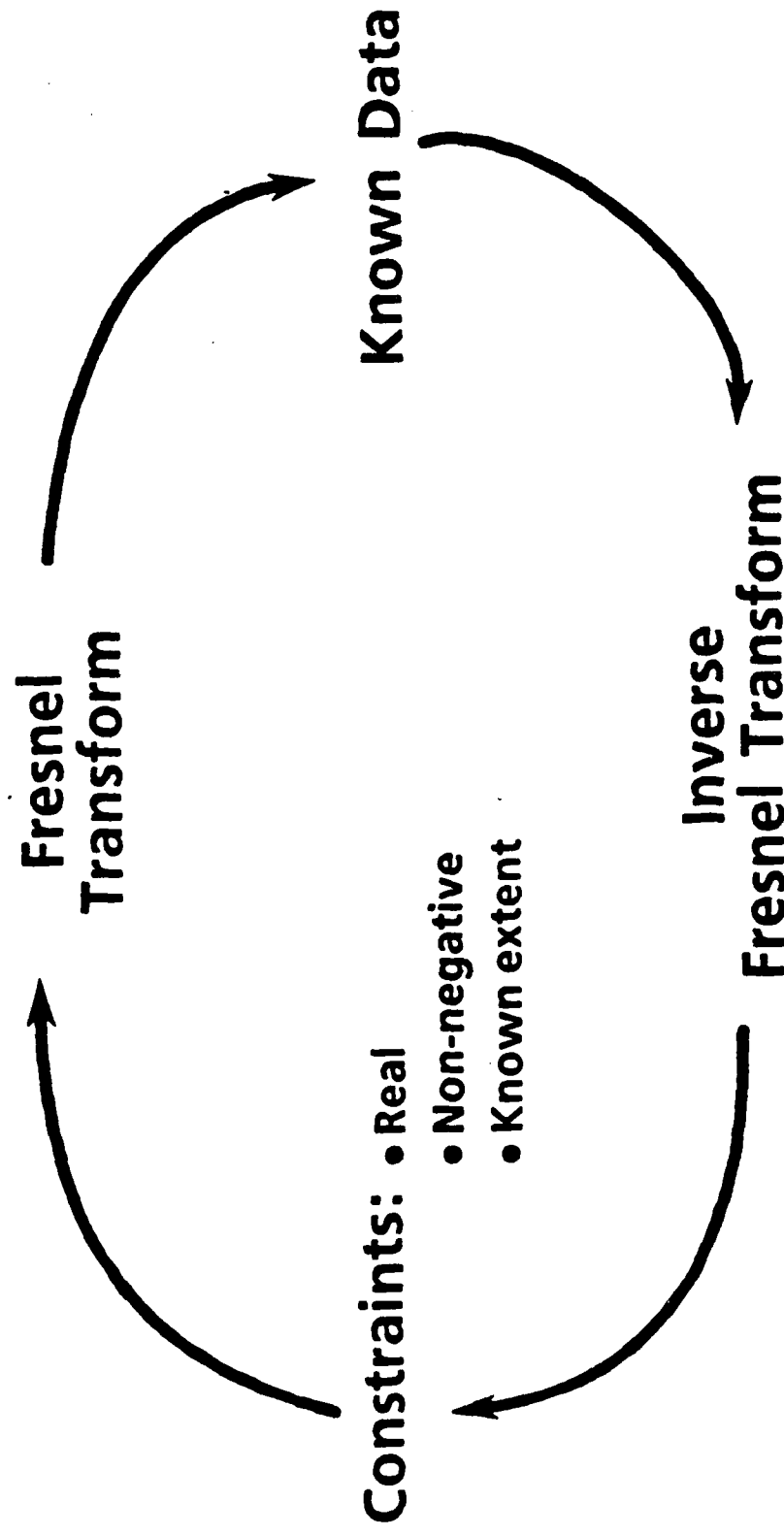
$$\alpha_1 = (1 - d_1 / F) / (\lambda F)$$

Number of Fresnel Zones

$$Z_F = [\alpha_1 (x_{\max})^2] / 2$$

Image Retrieval

(Rolleston and George, 1986)



MAGNITUDE-ONLY RECONSTRUCTION

Given Magnitude of Fresnel-zone Transform

$$|G(f_x, f_y)|$$

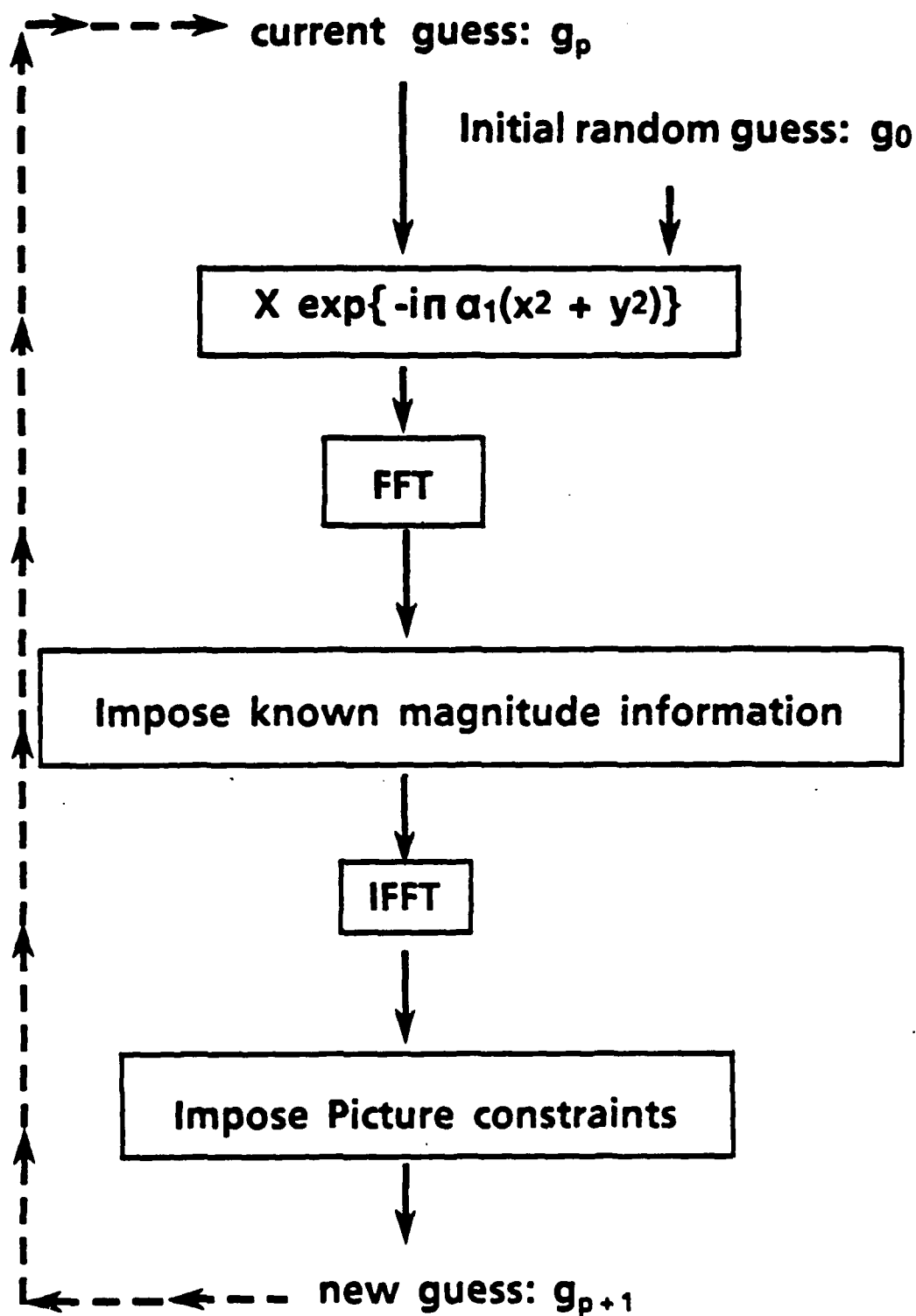
and constraints on $g(x, y)$

$g(x, y)$ is real

$g(x, y)$ is non-negative

$g(x, y)$ has a known size

Find: $\exp\{i\Phi(f_x, f_y)\}$ and $g(x, y)$



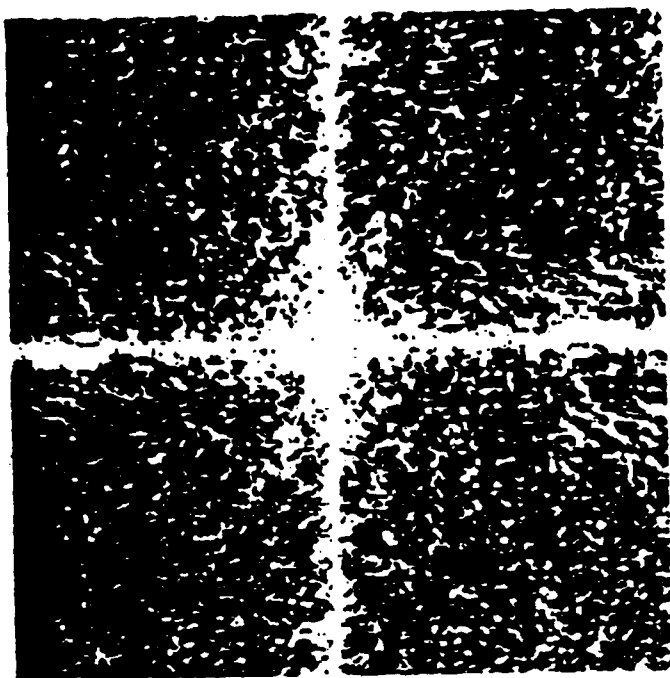
**Iterative Technique of Image
Reconstruction from Magnitude Information**



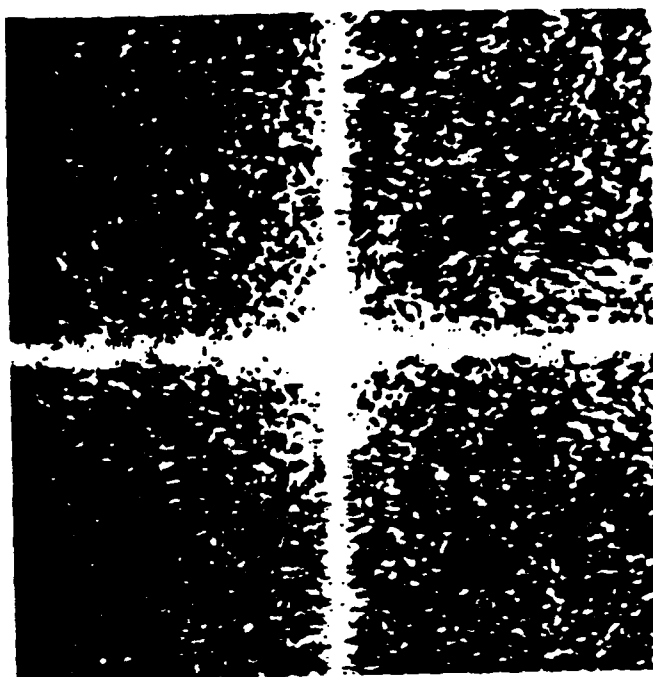
Original Image

256 x 256 Pixels

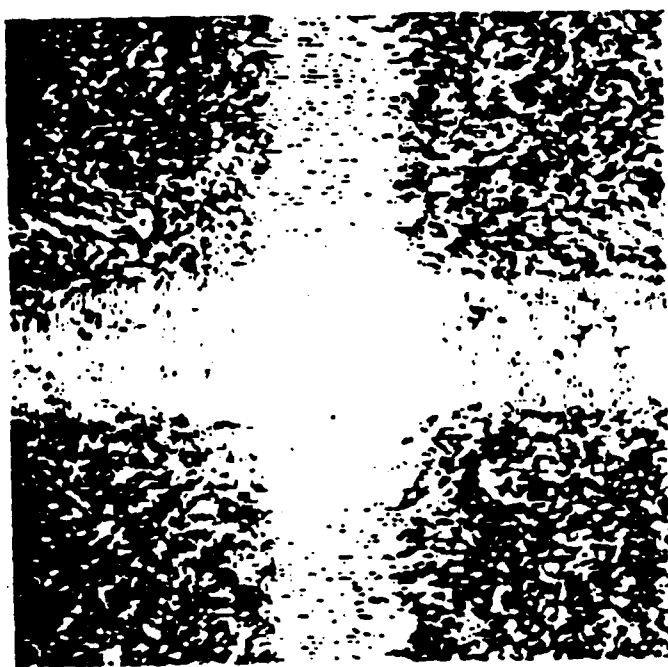
256 Gray Levels



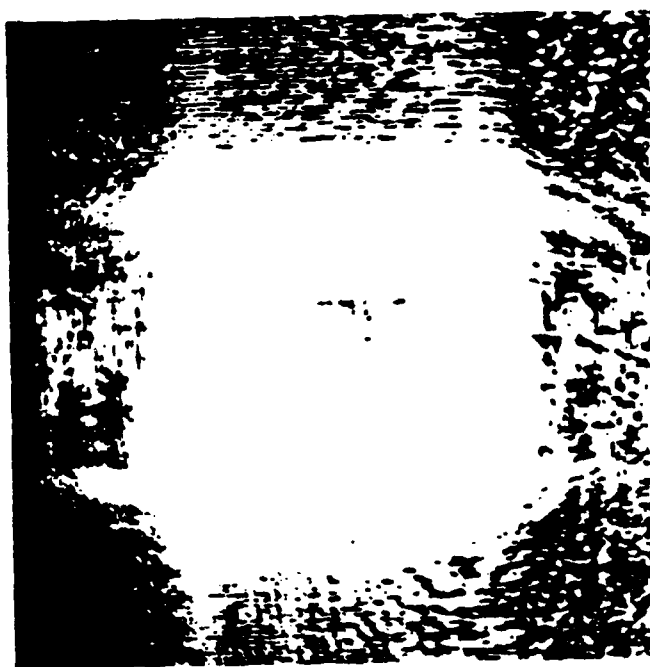
(a) $Z_F = 0.0$



(b) $Z_F = 0.5$

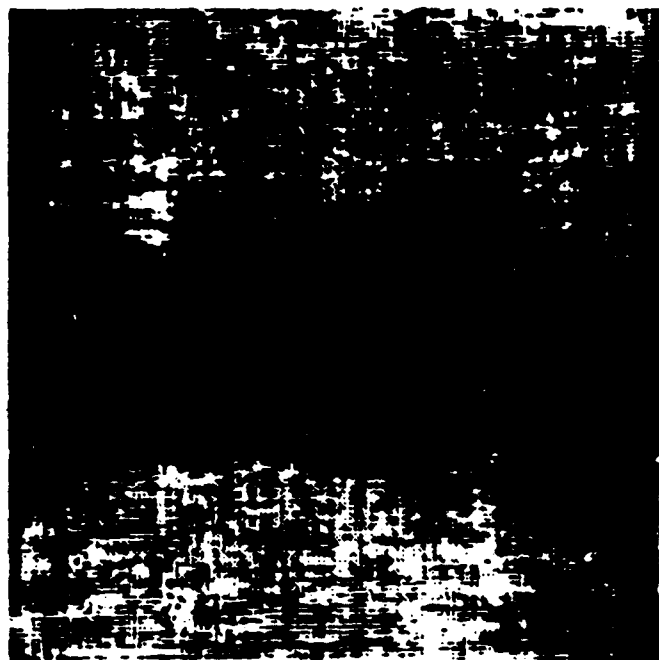


(c) $Z_F = 3.0$



(d) $Z_F = 8.0$

Given Magnitude Data



(a) $Z_F = 0.0$



(b) $Z_F = 0.5$



(c) $Z_F = 3.0$



(d) $Z_F = 8.0$

Magnitude-only Reconstructions

PHASE-ONLY RECONSTRUCTION

Given Phase of Fresnel-zone Transform

$$\exp\{i\Phi(f_x, f_y)\}$$

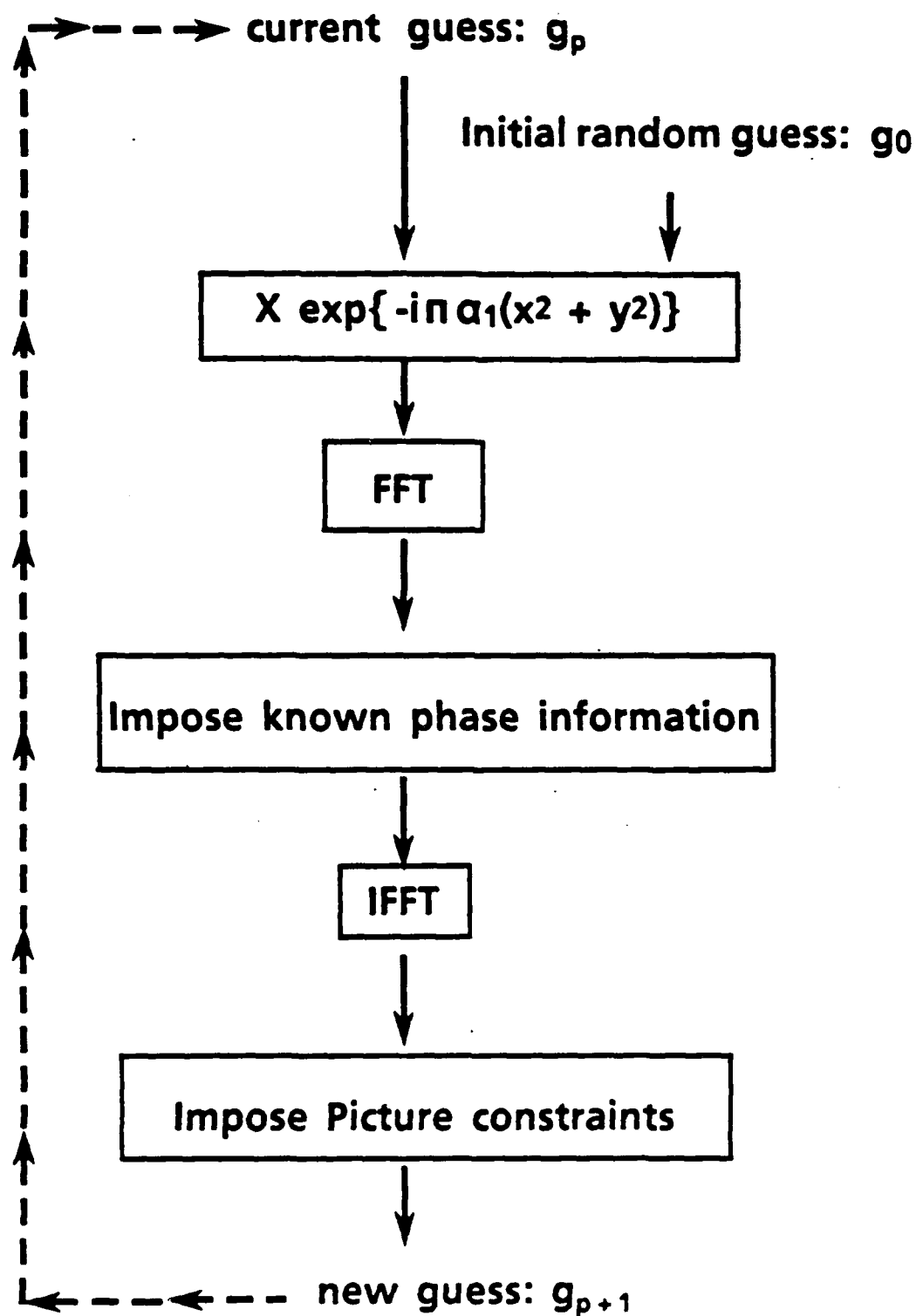
and constraints on $g(x, y)$

$g(x, y)$ is real

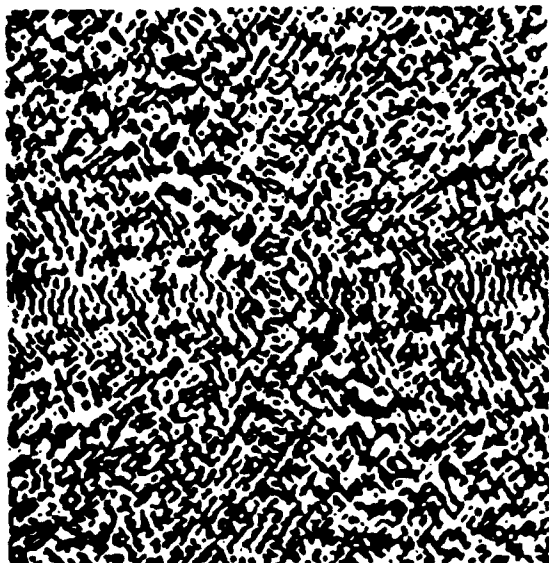
$g(x, y)$ is non-negative

$g(x, y)$ has a known size

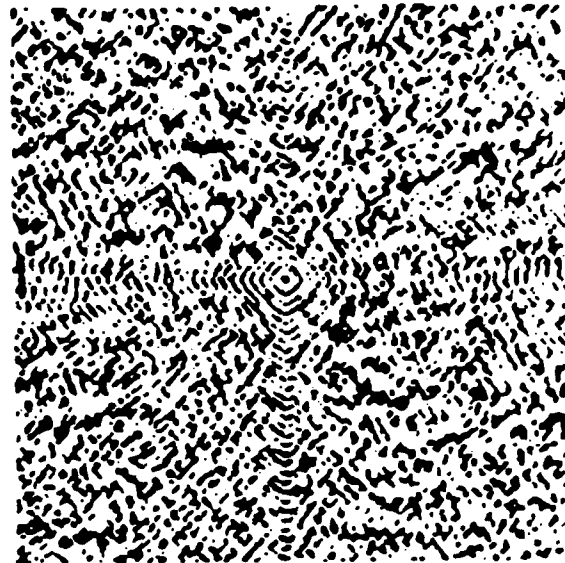
Find: $|G(f_x, f_y)|$ and $g(x, y)$



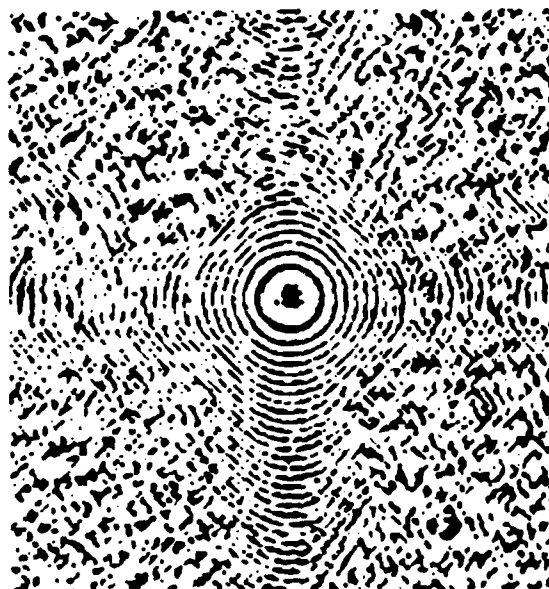
**Iterative Technique of Image
Reconstruction from Phase Information**



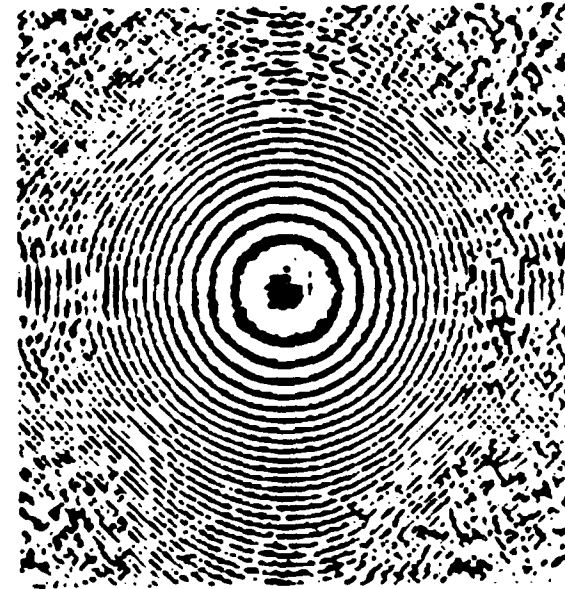
(a) $Z_F = 0.0$



(b) $Z_F = 0.5$



(c) $Z_F = 3.0$



(d) $Z_F = 8.0$

Given Phase Data



(a) $Z_F = 0.0$



(b) $Z_F = 0.5$



(c) $Z_F = 3.0$



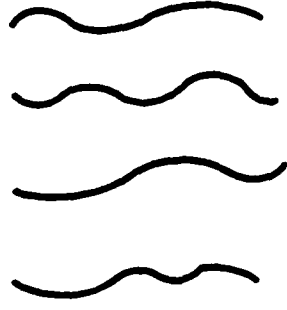
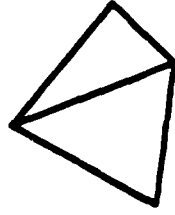
(d) $Z_F = 8.0$

Phase-only Reconstructions

Conclusions:

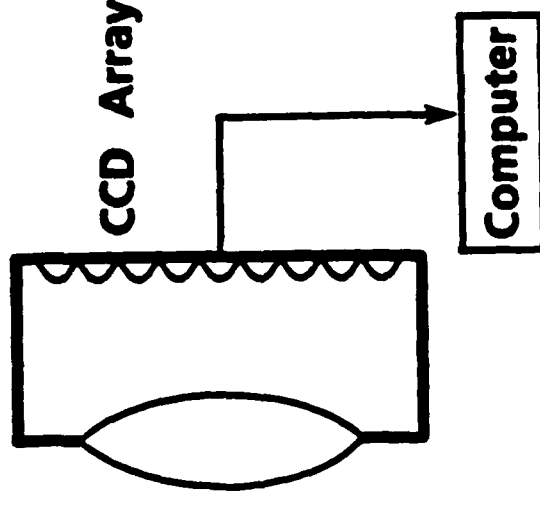
- **Image recovery from partial Fresnel-zone information has been demonstrated.**
- **Phase-only reconstructions have a slight degradation when moving out of the Fourier plane and into the Fresnel region.**
- **Magnitude-only reconstructions are greatly improved when moving out of the Fourier plane and into the Fresnel region.**

Problem: Imaging Through Turbulence



10 Hz Fluctuations

Aplanatic Patches (10-20 cm)



Improve Image Quality:

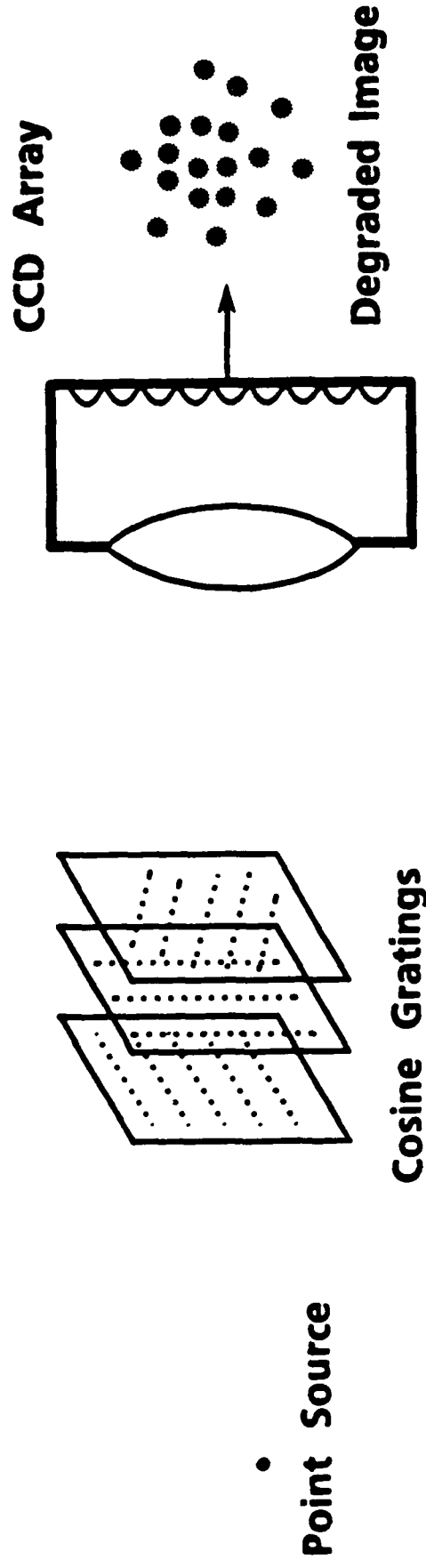


Phase Conjugation

Image Recovery

Adaptive Optics

Degradation Model (short exposure)



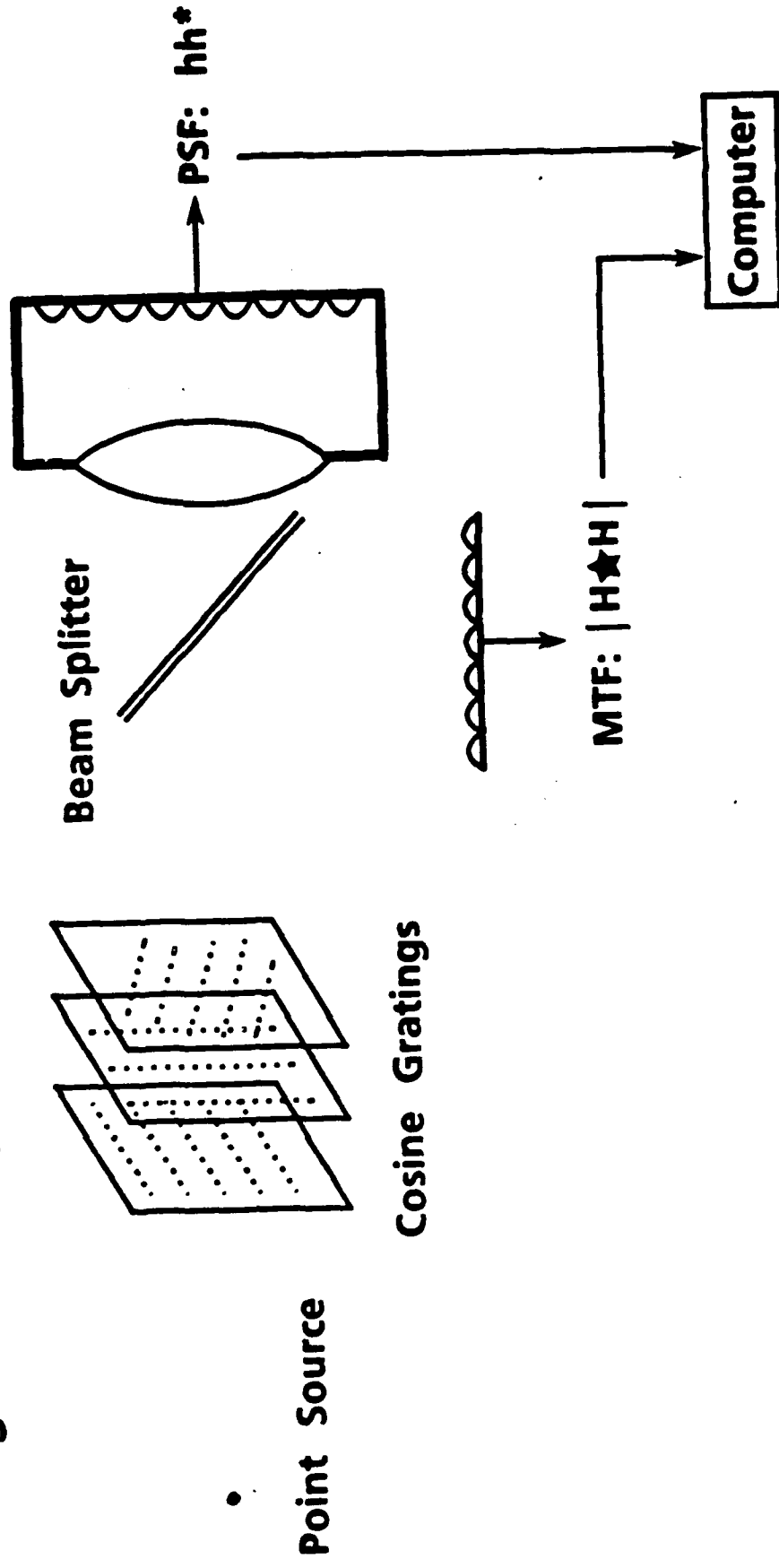
Point Spread Function

$$p(x, y) = \sum_{i=1}^N b(x - x_i, y - y_i) \quad \text{Sum of shifted blur functions}$$

Inverse Filter Function

$$P(f_x, f_y) = B(f_x, f_y) \sum_{i=1}^N \exp(in[x_i f_x + y_i f_y])$$

Image Recovery: Current Research



Use Image Recovery techniques to recover amplitude impulse response and optical transfer function.

Selected Bibliography

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Hayes, Lim, and Oppenheim, "Signal reconstruction from phase or magnitude," *IEEE Trans. Acoust. Speech Signal Process.* ASSP-28, 672-680 (1980).

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Youla and Webb, "Image restoration by the method of convex projections: Part 1-theory," *IEEE Trans. Med. Imag.* MI-1, 81-94 (1982).

CENTER FOR NIGHT VISION AND ELECTRO-OPTICS

CECOM Tests Automatic Target Recognizer

The Army reports a significant advance in its development of a new generation of night vision equipment with the completion of tests on an automatic target recognizer.

Test director John Farr of the Army Communications-Electronics Command (CECOM) Center for Night Vision and Electro-Optics, Fort Belvoir, VA, said the successful tests produced 14 sets of videotapes of collected imagery. "The data will be used in the development of night vision equipment designed to reduce the pilot's workload and the time it takes to find a target," Farr said.

Tests were conducted with a sensor package mounted on the nose of a helicopter. A video screen inside the aircraft displayed target objects and the heat they emanated. The imagery was recorded on high-resolution videotape.

The objective was to collect continuous 8"-5-line imagery of different types of military targets. Four target types were used — tank, armored personnel carrier, truck and high mobility, multi-wheeled vehicle. More than 70 low-altitude runs were made over two weeks at CECOM's Central Oregon Test and Evaluation Facility.

Using the collected data, engineers will "teach" the automatic target recognizer to detect and classify targets from

sensor output. As technology develops, the target recognizer will be able to discriminate among friendly and hostile vehicles and aircraft, prioritize targets and direct fire toward the highest threat target.

Eventually the automatic target recognizer will be mounted on remotely piloted vehicles. With the ability to differentiate between live and spurious enemy warheads, the automatic target recognizer will help drivers of tanks and other land vehicles navigate and lock in on targets.

The imagery collection effort involved the use of a unique night vision system employing a Type I utility helicopter with a target acquisition designator system.

An Army UH-1 helicopter was fitted with a nose-mounted support for two high-resolution imaging sensors. The tapes have two audio tracks, one carrying verbal instructions, the other continuous range information from the primary target to the target areas.

The Oregon National Guard provided eight target vehicles and drivers for the tests. Two M60A3 tanks, two M113 armored personnel carriers, two M35 2 1/2-ton trucks and two of the Army's new high mobility, multi-wheeled vehicles were split between the two target areas a little over six miles apart.

5. LIST OF ATTENDEES

OPTOELECTRONIC WORKSHOP AUTOMATIC PATTERN RECOGNITION

April 7, 1988

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