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ADRIATICO CONFERENCE ON FOURIER OPTICS AND HOLOGRAPHY

OPTICAL CORRELATION:

APPLICATIONS VIEWGRAPHS

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OPTICAL CORRELATION: PRINCIPLES, TECHNIQUES AND APPLICATIONS

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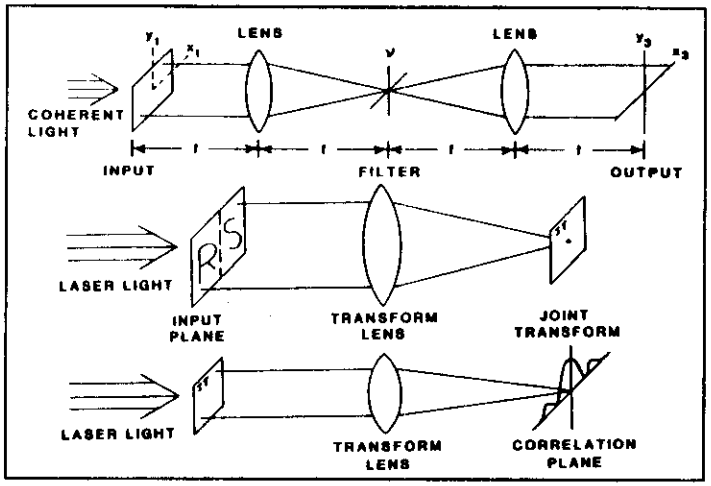
OPTICAL CORRELATION: PRINCIPLES, TECHNIQUES AND APPLICATIONS

SUMMARY

- PRINCIPLES OF OPTICAL CORRELATION
  - Basic Mathematical formalism
- DEVICES FOR OPTICAL CORRELATION
  - Sources
  - Modulators
- TECHNIQUES
- APPLICATIONS

FREQUENCY PLANE CORRELATOR FPC



- at P2: G(u,v) H (u,v)
- antitrasforming leads to correlation g*h
- If H(u,v) is the antitrasform of pattern to be detected, then it is a Matched Spatial Filter
- Adaptive filtering, MFS synthesis with SLM's

SPATIAL MODULATORS FOR OPTICAL CORRELATION

- AMPLITUDE ONLY
  - Apertures/masks
  - Liquid Crystals TV's (LCTV's)
- AMPLITUDE AND PHASE
  - Computer-generated holograms (CGH's)
  - Spatial light modulators (Light valves)
- PHASE-ONLY MODULATORS
  - Etched quatrz plates
  - Spatial light modulators
- TIME-SPACE CONVERSION
  - Acousto-optical modulators (AOM's)

EXAMPLE OF SLM FOR OPTICAL CORRELATION

Figure 4.3 The Hughes liquid crystal light valve. (Reproduced by kind permission of Hughes Aircraft Company.)

OPTICALLY ADDRESSED SPATIAL LIGHT MODULATORS

SLM	Size	Mode of Operation	Sensitivity	Frame Time (ms)	Resolution (lp/mm)	Contrast Ratio	Optical Flatness	References
PROM	25 mm diam.	Reflection	5 μJ/cm²	33	6	10^2:1	λ/10 (r.m.s.)	[58]
Priz	18 mm diam.	Transmission	5 μJ/cm²	100	10			[60]
LCLV	(2 inch)²	Reflection	8 mW/cm²	80	25†	100:1	< 3λ/4 (pk-to-pk)	[54, 77]††
BSO LCLV	(15 mm)²	Reflection	380 μW/cm²	165	31	21:1	λ	[68]††
a-Si LCLV	(1.5 inch)²	Reflection	20 μW/cm²	50	35			[70]
Microchannel SLM (× 1699)	16 mm diam.	Reflection	30 nJ/cm²	150	10	> 10^3:1		[89]
a-Se ruticon	1.5 inch diam.	Reflection	1 μJ/cm²	8	14	22:1		[85]
Phototitus (a-Se/DKDP)	~(2 cm)²	Reflection	1 μJ/cm²	1	20	10:1		[82]
Ferpic (CdS/PLZT)	7.5 mm diam.	Reflection	20 μJ/cm²	0.1	20	4:1		[83]
Si LCLV p. diode	43 mm diam.	Reflection	40 μW/cm²	25	12	20:1	4 λ	[64]

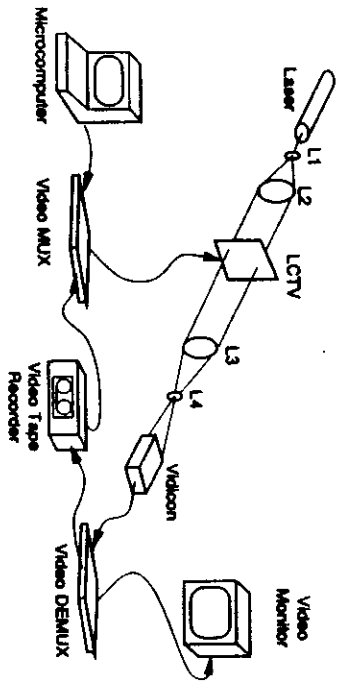
†Measured over circle of 16 mm diameter in centre of device.
††In these devices, the low frame time and high resolution can be obtained simultaneously at the write sensitivity quoted.

ELECTRICALLY ADDRESSED SPATIAL LIGHT MODULATORS

SLM	Size	Resolution† (lp/mm)	Frame Time	Contrast Ratio	Optical Flatness	References
LIGHT-MOD						
256-03	$(20\ mm)^2$	256 × 256	1 s (10 ms)††	10^3:1	λ/2	
128-03	$(10\ mm)^2$	128 × 128	250 ms (2 ms)††		λ/2	[90]
48-05	$(8.5\ mm)^2$	48 × 48	33 ms (700 μs)††		λ/2	
DMD	$(6.4\ mm)^2$	(9.8)	16 ms	30:1		[97]
CLV	$(20\ mm)^2$	800 × 500	33 ms	10^2:1		[101]
e-beam DKDP (Titus)	$(50–75\ mm)^2$	(20)	33 ms	10^2-10^3:1	< λ/4	[100]
e-beam thermoplastic (Lumatron)	$(1.5\ inch)^2$	(70)	1 s			[103]

†Or number of pixels.
††Frame rates for line-parallel address.

REAL-TIME JOINT CORRELATOR BASED ON LCTV SLM'S

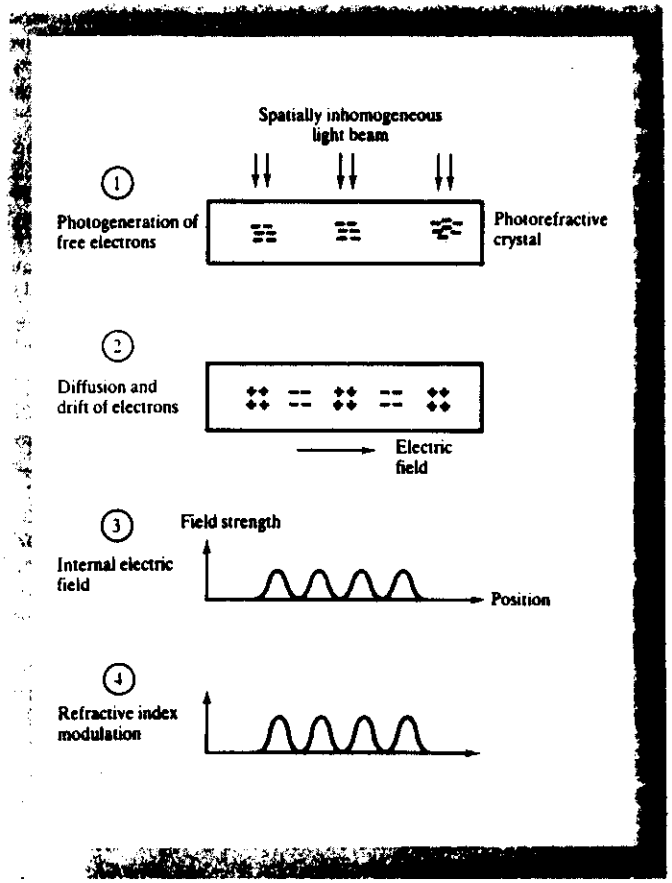


Recorded image mux-ed with stored image and joint-correlated in F-plane

MATERIALS FOR HOLOGRAM RECORDING

- PHOTOGRAPHIC EMULSIONS
- DICHROMATED GELATINS
- THERMOPLASTICS
- PHOTOREFRACTIVE MATERIALS
- PHOTOPOLYMERS
- PHOTORESISTORS

PRINCIPLE OF PHASE MODULATION IN PHOTOREFRACTIVE MATERIALS



HOLOGRAPHIC RECORDING MATERIALS FOR OPTICAL CORRELATION

Recording Material	Sensitivity ($\mu J/cm^2$)	Wavelength Range (Recording)	Thickness (μ)	Resolution (10^3 lp/mm)	Speed (ms)	Diffraction Efficiency (%)	Amplitude (A) or Phase (P) Modulation
Silver halide emulsion	10	blue to 750 nm	6–17	≤ 5	100	6	A
Dichromated gelatin	10^5	UV to 520 nm	1–13	> 5		80	P
Thermoplastics	100	blue to 1.15 μm	0.2–10	0.05–2.5 (peak)	250	32	P
Photorefractive BSO	300	blue	0.4–2 mm	0.03–1	20 (at 10 mW/cm^2)	0.3 (zero field) 25 (9 kV/cm)	P
Photochromics	10^5	488, 514, 633	variable	> 3	very fast	1	A
Photopolymer [116] DMP-128	10^4	visible	1–30	≤ 1.6	~ min	90	P
Photoresistors	10^5	UV to 500 nm	≤ 4	> 1	100	10	P

OPTICAL CORRELATION: SUMMARY OF APPLICATIONS 1

- **MILITARY**
  - Missile guidance
  - Vehicle guidance
  - Radar signal processing
  - Synthetic Aperture Radar
  - Aerial Photometry
- **ASTRONOMY/AERIAL PHOTOGRAPHY/PHOTOMETRY**
  - Astrophotography (speckle Masking)
  - Aerial photography
  - Aerial Photometry
  - Geographical Monitoring
- **SPACE EXPLORATION**
  - On-board vision systems

OPTICAL CORRELATION: SUMMARY OF APPLICATIONS 2

- SIGNAL PROCESSING
  - Multichannel spectrum Analysis (real time)
  - Optical radio (hopping signal detection)
  - Heterodyne transform
  - Variable matched filtering
  - Adaptive filtering
- INDUSTRIAL APPLICATIONS
  - Image processing and restoration
  - Image filtering/contrast enhancement
  - Pattern recognition: matching objects to templates
  - Robot guidance
  - Quality control
- BIOMEDICAL APPLICATIONS
  - Image restoration and pattern recognition (CAT, NMR, ECG, OFA)

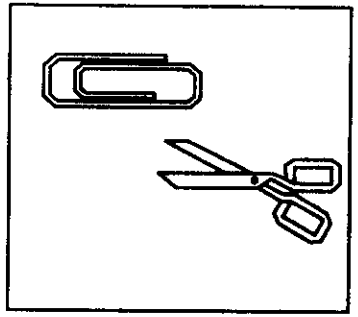
INDUSTRIAL APPLICATIONS OF OPTICAL CORRELATION

- Quality control of manufacts
- Recognition of objects in production lines
- Robot guidance
- In-production monitoring of polymer growth/particle sizing

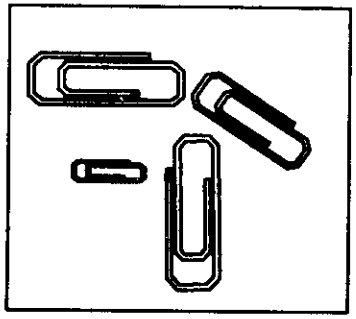
GENERAL PROBLEMS RELATED TO INDUSTRIAL APPLICATIONS OF OPTICAL CORRELATION

- Scale and rotation invariance
- Size of the target
- Throughput
- Multiple images
- 3-D monitoring
- Real-time operation
- Simple architectures

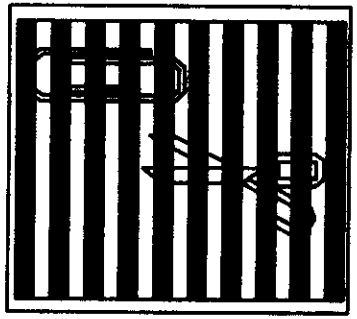
GENERAL PROBLEMS RELATED TO INDUSTRIAL APPLICATIONS OF OPTICAL CORRELATION



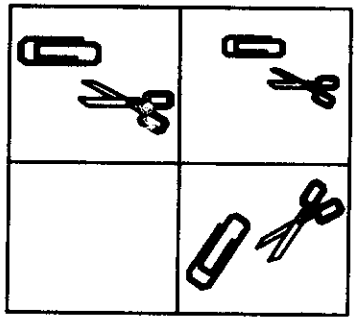
a) simple



b) scale and rotation



c) background



d) multiple images

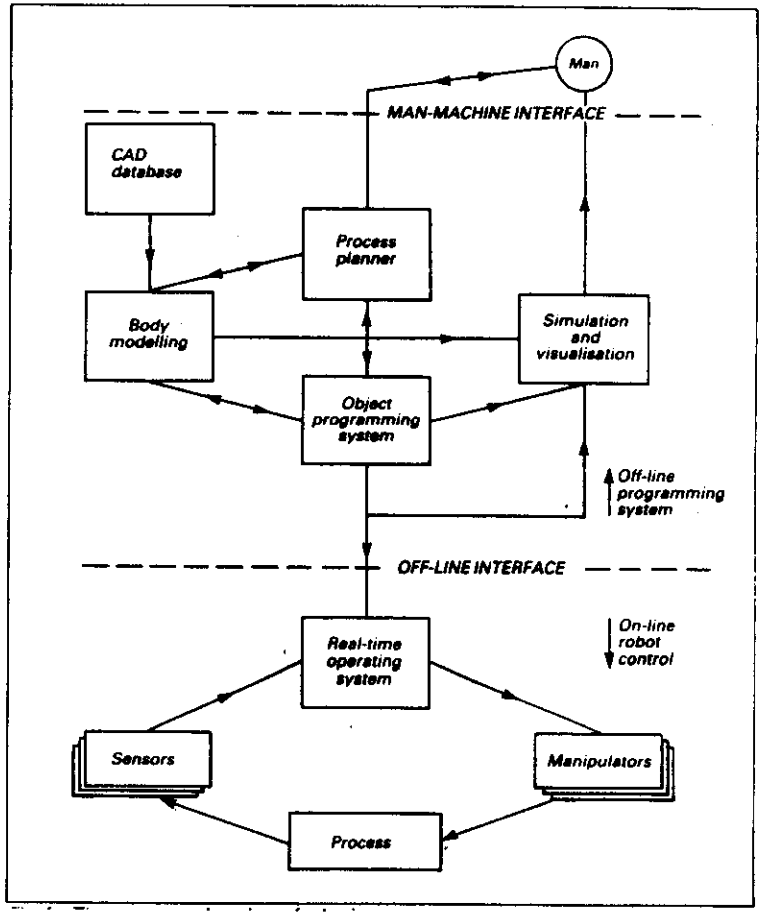
WHY OPTICAL?

- Frame grabbers/PC computer performances
  - 512x512 typical camera dimensions
  - Real time grabber acquisition (30 frames/s)
  - Arithmetic processing w/o array proc.: minutes!
  - Arithmetic processing w/ array proc.: seconds!

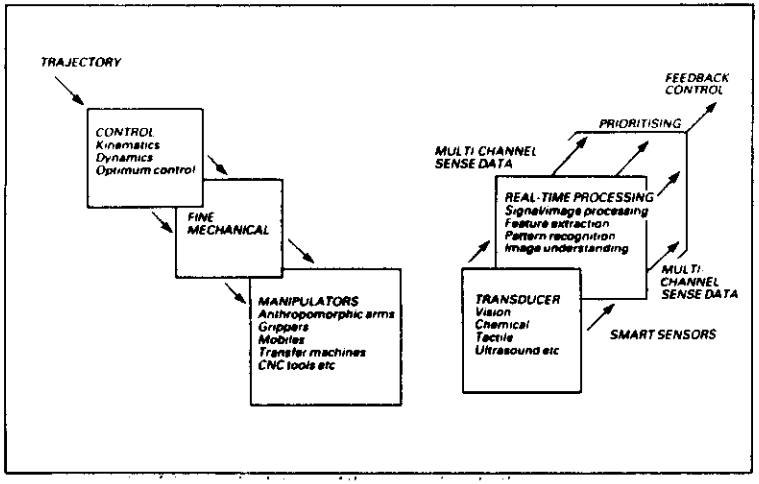
WHY FOURIER?

- Insensitivity to displacement
- Multiplication easier than correlation

THE PROGRAMMING VIEW OF ROBOTICS



SENSORS AND MANIPULATORS IN ROBOTICS

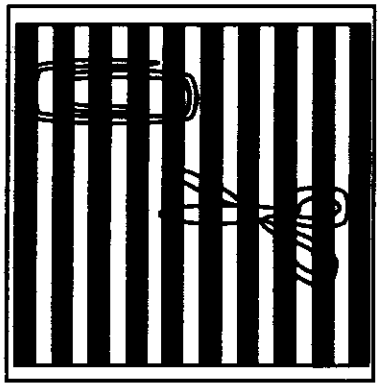


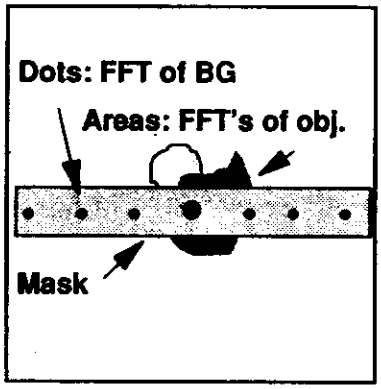
SCALE- AND ROTATION INVARIANT TECHNIQUES FOR OPTICAL CORRELATION

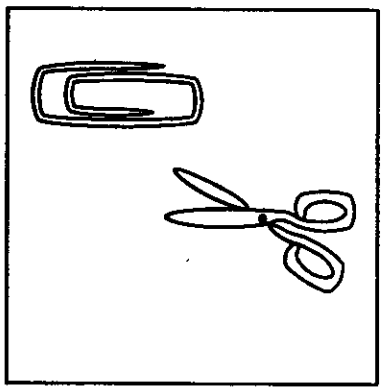
- Scale invariance
  - Mellin Transforms
  - Logarithmic radial harmonic filters
  - Anamorphic correlation
- Rotation invariance
  - Circular harmonic filtering
  - Optimum feature extraction

DETECTION OF OBJECTS IN A BACKGROUND USING FOURIER FILTERING TECHNIQUES

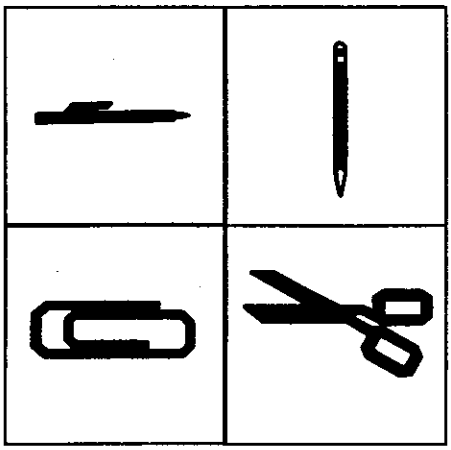
Object plane | **Fourier plane** | **Image plane**



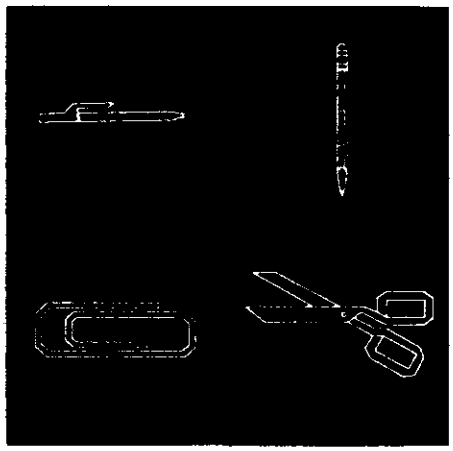




ADDITIVITY OF FOURIER-FILTERED IMAGES



Non-filtered image
Non-additive



Filtered image
Additive

Made in Italy

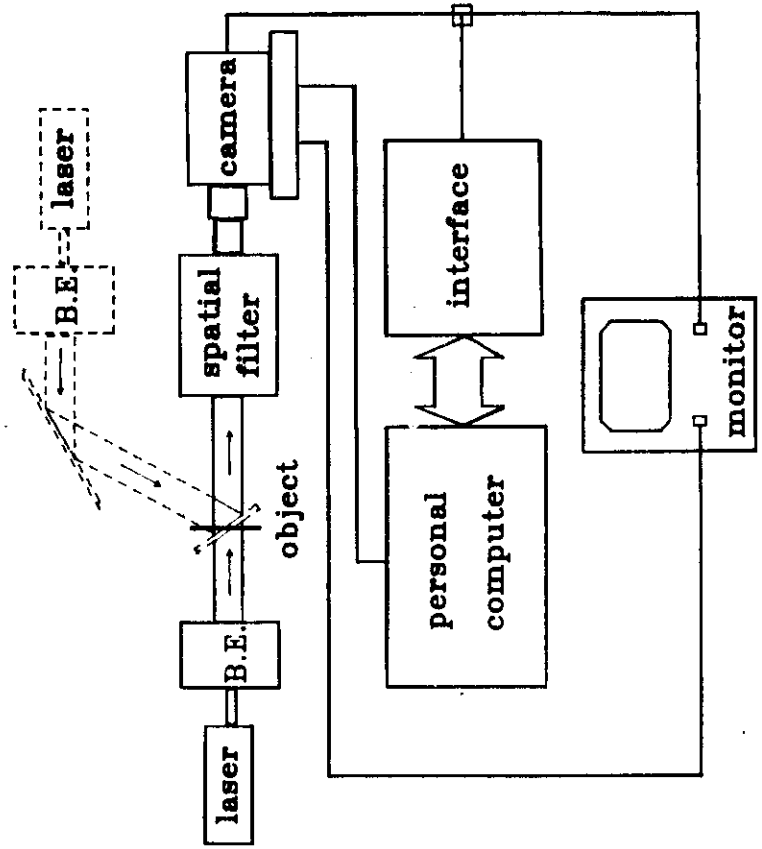
EXAMPLES OF INDUSTRIAL APPLICATIONS OF OPTICAL CORRELATION AND FOURIER FILTERING

- Real time spatial filtering for dark-field contrast enhancement
  - Brescia (Docchio et al., 1989)
- Pattern recognition with computer-generated binary holograms
  - Nerviano (Vanotti et al., 1989)
- Optical particle sizing with the Chahine inversion scheme
  - Milano (Bassini et al., 1989)
- Coherent Fourier image processing
  - Trieste (Sirotti and Rizzato, 1989)

N.	OPTICAL CORRELATION

LAYOUT OF A FOURIER FILTERING SYSTEM FOR TRANSMISSION/REFLECTION CONTRAST ENHANCEMENT

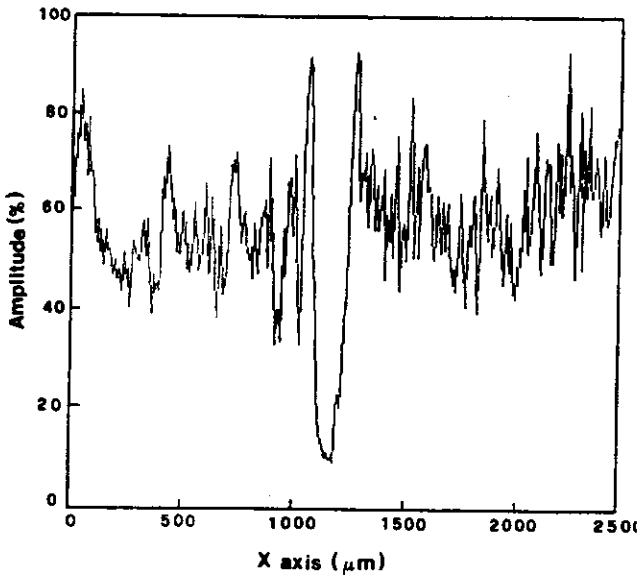
(Docchio et al., 1989)



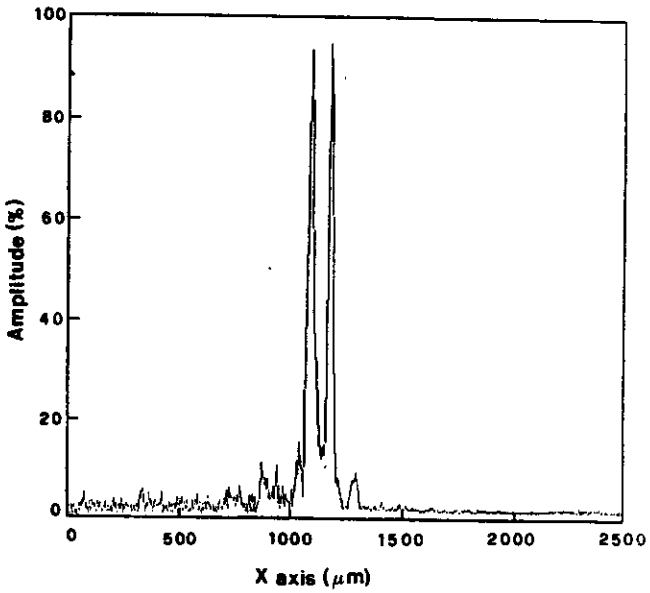
e-Ne laser
eam
xpander with
p Spatial
lter
/p spatial
lter setup
amera
cquisition
nit
C interface

DARK FIELD CONTRAST ENHANCEMENT WITH FOURIER FILTERING: A METALLIC WIRE

(Docchio et al., 1989)



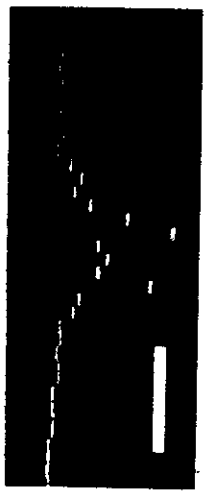
Unfiltered



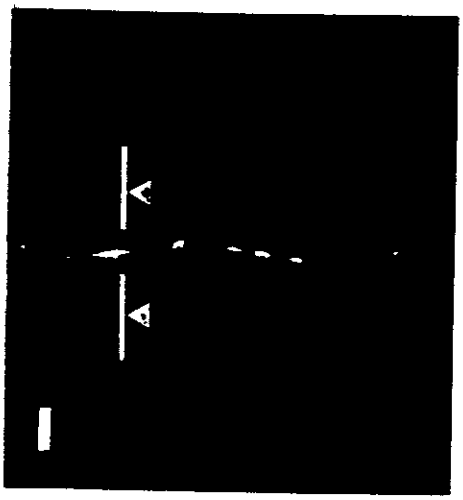
Filtered

DARK-FIELD CONTRAST ENHANCEMENT: DETECTION OF [illegible] ON GLASS SURFACES

(Docchio et al., 1991)

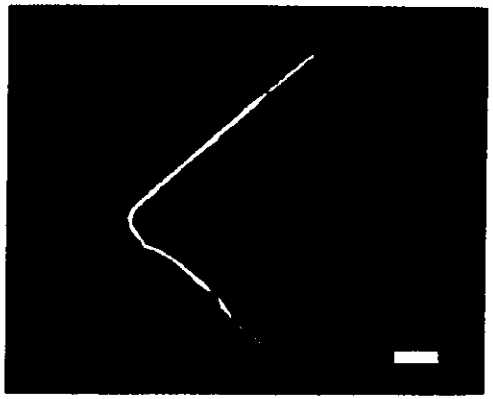


I vs x

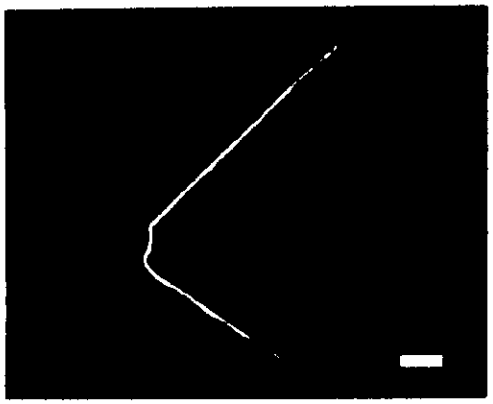


2-D

EDGE-ENHANCED PROFILES OF MECHANICAL TOOLS WITH DFCE (Decchio et al., 1989)

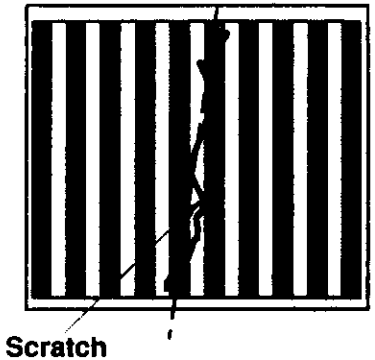


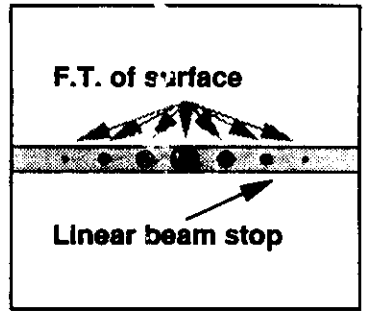
a)

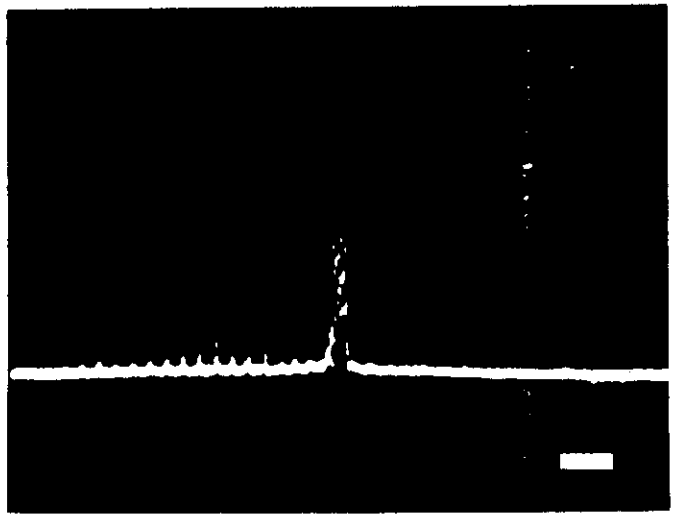


b)

DETECTION OF A SCRATCH ON A RULED TRANSPARENT SURFACE (Decchio et al., 1989)







Scratch at 15 °with respect to rules

OPTICAL PARTICLE SIZER USING THE CHAHINE INVERSION TECHNIQUE (Bassini et al., 1989)

- Dispersion of granules analysed using spherical wave
- Fraunhofer approximation for diffracted field
- Ring-shaped detector geometry with centered hole
- Scale is changed by cell translation

PATTERN RECOGNITION WITH COMPUTER-GENERATED HOLOGRAMS (Psaltis et al., 1985)

- CGH's based on Psaltis's technique
- MOLSM as spatial modulator
- Applications to industrial pattern recognition in robotics

COMPARISON BETWEEN MATCHED, PHASE-ONLY, AND BINARY PHASE-ONLY FILTERS

potential

BIOMEDICAL APPLICATIONS OF OPTICAL CORRELATION

- Automated image processing
- Recognition of patterns in relation to pathology/ageing
- Studies on the morphogenesis of biological structures through the analysis of their fractal properties

PROBLEMS RELATED TO BIOMEDICAL ARRLICATIONS OF OPTICAL CORRELATION

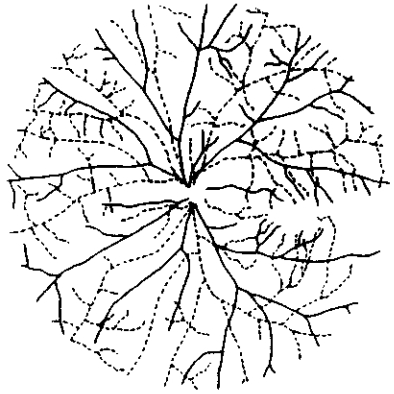
- Biological tissues exhibit highly irregular, non-periodic structures
- Fractal geometries often exhibited
- Diagnosis often presents less stringent requirements of real-time operation
- Fewer scale- and orientation problems, but more problems related to templates
  → matched filtering difficult

EXAMPLES OF BIOMEDICAL AREAS FOR THE APPLICATION OF ORTICAL CORRELATION

- Cardiology
  - Identification of stenotic vessels from angiograms
  - Analysis of ECG maps
- ORL
  - Studies of lung morphogenesis and structural/physiological evolution
- Ophthalmology
  - Analysis of fundus photographs and fluorescein angiograms in relation to the diagnosis of diabetic retinopathy/senile mavular degeneration

EXAMPLES OF BIOMEDICAL IMAGING: FLUORESCEIN ANGIOGRAPHY

a) Photograph



b) Digitized vessel profile for the study of fractal patterns

FUTURE OF OPTICAL CORRELATION /FILTERING APPLICATIONS (but I may be wrong!)

- Industrial applications of optical correlation will have to consider the tremendous increase in the performances of digital image processors

- Biomedical applications of optical correlation still need full exploitation. Template matching in the Fourier plane may help diagnosis. Potential for follow-ups.