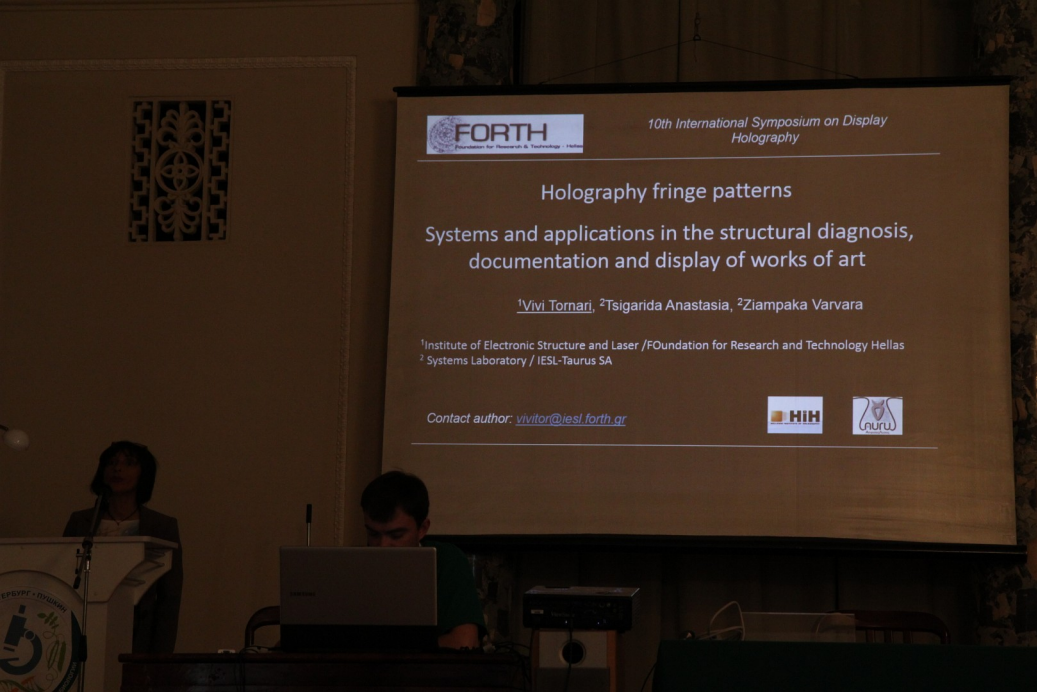
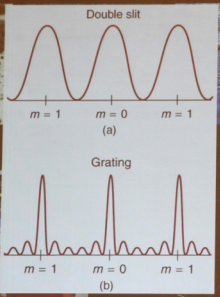
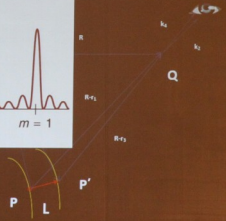
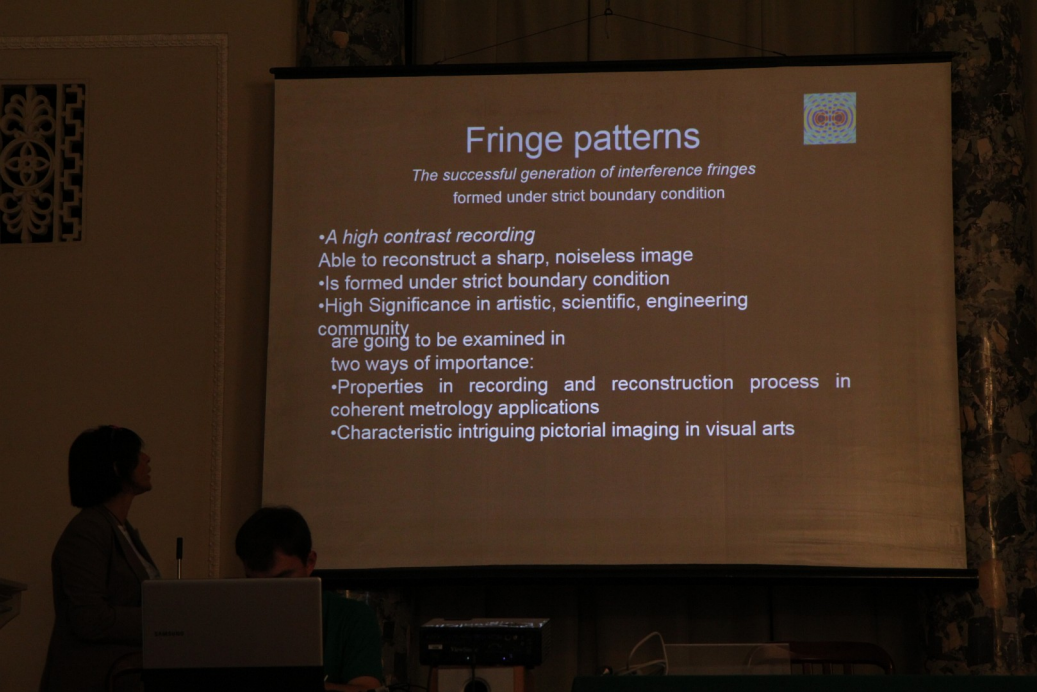

FORTH
Foundation for Research & Technology - Hellas
10th International Symposium on Display Holography
Holography fringe patterns
Systems and applications in the structural diagnosis, documentation and display of works of art
[1]Vivi Tornari, [2]Tsigarida Anastasia, [2]Ziampaka Varvara
[1]Institute of Electronic Structure and Laser /FOundation for Research and Technology Hellas
[2] Systems Laboratory / IESL-Taurus SA
Contact author: vivitor@iesl.forth.gr
HIH

Fringe patterns

natural , physical and artificial mysterious entities

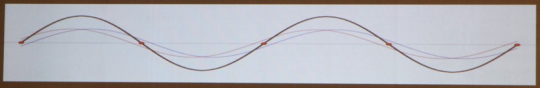





Fringe patterns
The successful generation of interference fringes
formed under strict boundary condition
•A high contrast recording
Able to reconstruct a sharp, noiseless image
•Is formed under strict boundary condition
•High Significance in artistic, scientific, engineering
community
are going to be examined in
two ways of importance:
•Properties in recording and reconstruction process in coherent metrology applications
•Characteristic intriguing pictorial imaging in visual arts

Coherent light interference

Coherent laser light interference:
$f = \sin\theta 1 - \sin\theta\ 2\ \lambda$
created by superposition of two
mutually coherent waves



Wave superposition: Interference of left travelling (green) and right travelling (blue) waves in one dimension, resulting in final (red) wave (image source:Wikipedia)

Holography

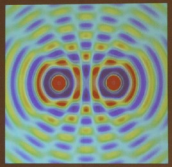
Primarily fringes:

1) Significant in accurate reconstruction of the primary waves
2) Determine hologram's aesthetic, artistic, application value

Holographic Interferometry

Secondary fringes :

Represent displacement in two positions of the subject



Fringe patterns

Fringe patterns: visual aid to identify structural discontinuity

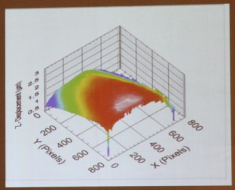
Benefits of DHSPI:

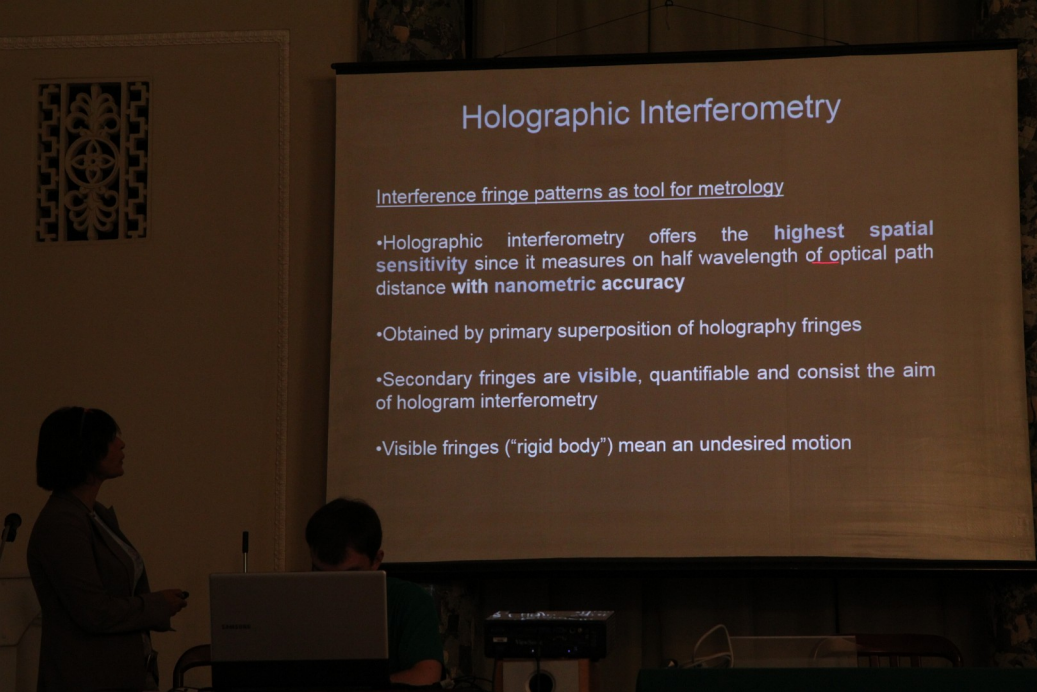
1) non destructive
2) non contacting
3) non invasive
4) highly accurate

Allows the researcher to:

- identify a variety of structural problems
- prognoses the state of condition
- provide a priority map of restoration strategy

DHSPI



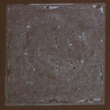

Holographic Interferometry
Interference fringe patterns as tool for metrology
•Holographic interferometry offers the highest spatial sensitivity since it measures on half wavelength of optical path distance with nanometric accuracy
•Obtained by primary superposition of holography fringes
•Secondary fringes are visible, quantifiable and consist the aim of hologram interferometry
•Visible fringes ("rigid body") mean an undesired motion

DHSPI in artwork analysis

The invisible becomes visible in coded pattern form and displacements studied allow applications in the majority of art structural diagnosis conservation problems

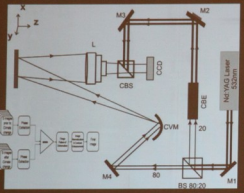
Example Risk priority map

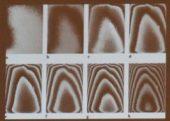
SYSLAB real time inspection of icons

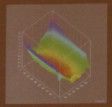


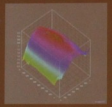
Rafael structural diagnostics & documentation
(National Gallery of Athens)

RAPID INTERFEROMETRIC FULL-FIELD SHAPE REACTION RECORDING FROM SURFACE MONITORING





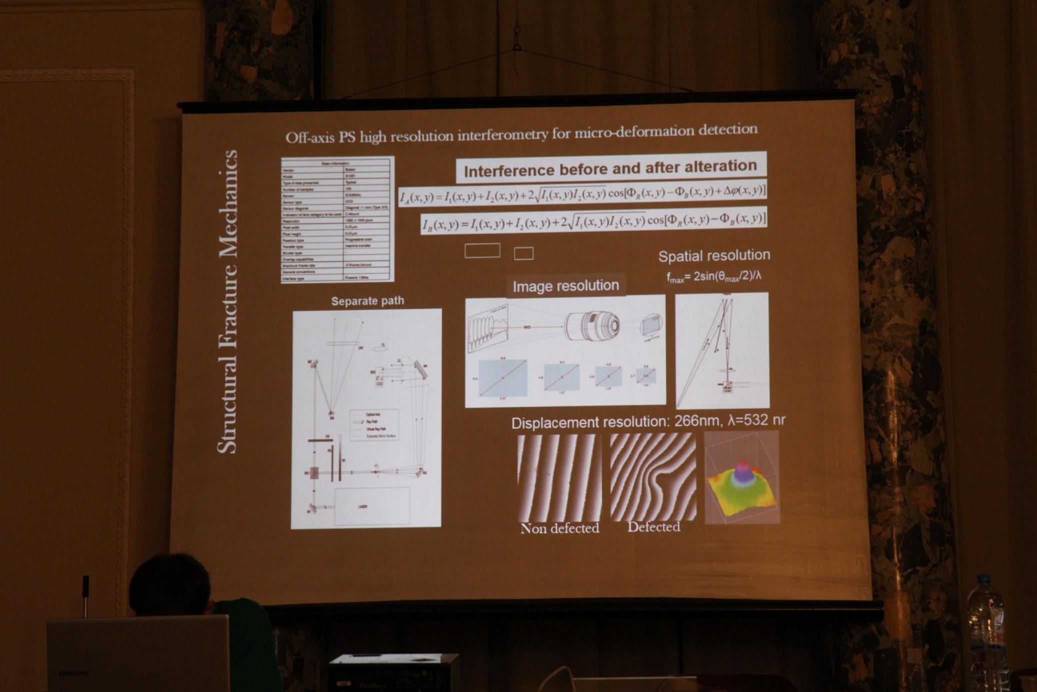




Examples of interferograms recorded of surface movement of model painting after a climate change from 10.5% to 44% RH following *top, left to right* **1 s, b 8 s, c 16 s, d 22 s,** *bottom, left to right* **e *31 s*, f 36 s, g 43 s, h 48 s (constant T, EMC≈days)**

Tornari V. et al., Sensors ***2008, 8, 8401-8422;***

Bernikola et al., Appl Phys A (2009) 95: 387–399

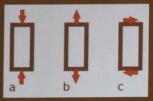

Structural Fracture Mechanics
Off-axis PS high resolution interferometry for micro-deformation detection
Interference before and after alteration
$I_A(x,y) = I_1(x,y) + I_2(x,y) + 2\sqrt{I_1(x,y)I_2(x,y)}\cos[\Phi_R(x,y) - \Phi_B(x,y) + \Delta\varphi(x,y)]$
$I_B(x,y) = I_1(x,y) + I_2(x,y) + 2\sqrt{I_1(x,y)I_2(x,y)}\cos[\Phi_R(x,y) - \Phi_B(x,y)]$
Spatial resolution
$f_{max} = 2\sin(\theta_{max}/2)/\lambda$
Image resolution
Separate path
Displacement resolution: 266nm, λ=532 nr
Non defected
Defected

Structural Fracture Mechanics

In materials science, the strength of a material is its ability to withstand an **applied stress** without failure.

$$\sigma = F / A \ (N/m^2)$$

(uniaxial stres s, F Force, A area)

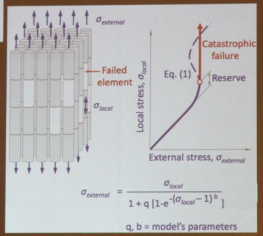


Two typical **deformation** scenarios:

A. DEFECT A localized failure does NOT cause immediate collapse of the entire structure

B. FAILURE The entire structure fails immediately after one of its components fails

Model	Solid with a crack	Multi-component structure with a failed component
Defect driving force	Stress intensity factor	Overload stress
System property	Fracture toughness	Reverse ability / structural robustness



The theory predicts reserve ability of the complex system and the critical external stress.

Ability depends on critical number of structural elements that define whether the system has reserve ability or not.

Deformation analogy in artwork structural defect generation

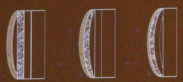
Structural Fracture Mechanics

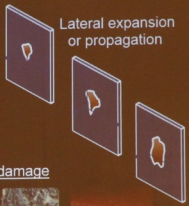
Definition

In artwork structural mechanisms due to aging or accidental overload the structure critical elements deformation leads to localised failure defined as :

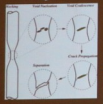
- Lost of material continuation, termed cracks
- Loss of adhesion between surfaces, termed detachments
- Loss of cohesion in layered surfaces, termed delaminations
- Loss of constituent material strength, termed stressed area

Artworks are composites with complex construction and inhomogeneous materials



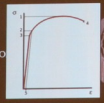


Lateral expansion or propagation



Detachment expansion vertical to surface, subsurface, bulk

Visible damage

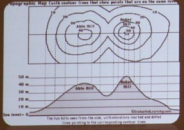


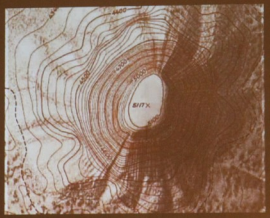
Cracking expansio and failure

Structural Fracture Mechanics

Information retrieve

- A Fringe pattern is a a visual representation of displacement
  - The surface witness stresses from internal defects
- The surface response generates full field fringe pattern formation with localised features representing local displacements
- The analysis leads to "topographic map" and risk evaluation



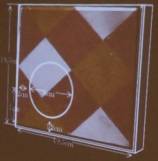


Micro-deformation detection for CH conservation and restoration processes

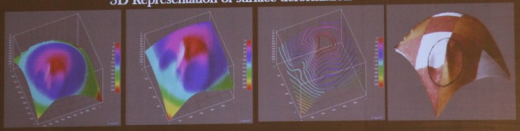
Exemplary results

Construction:

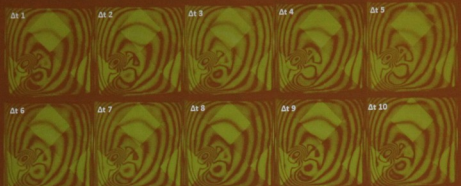
- Brick support, intonaco and arriccio
- Buon fresco technique
- ≈5mm deep internal detachment between intonaco and arriccio with application of circular organic material soluble in water 8cm diameter



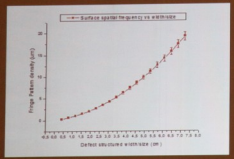
3D Representation of surface deformation

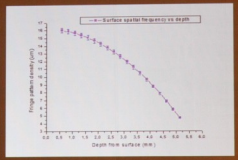


Results



Normalised graphs of defect detection according to the size and its depth in regards to the surface in terms of fringe pattern visibility determined by spatial frequency on the surface





Validation methodology

The anticipated method to validate defect type relies on the experimental verification between the fringe patterns generated by controlled known defects to fringe - patterns generated by unknown defects

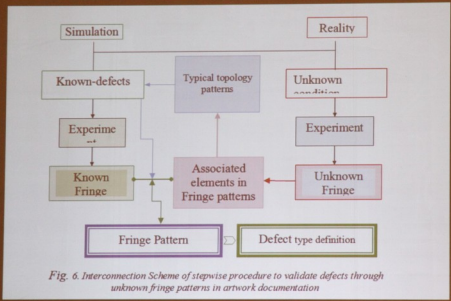


Fig. 6. Interconnection Scheme of stepwise procedure to validate defects through unknown fringe patterns in artwork documentation

Fringe Pattern Classification

					
	Circular Fringes	**Curved Fringes**	**Dead-end Fringes**	**Density-changed Fringes**	**Direction changed Fringes**
Features	*Closed* and open curves, *smooth* direction change, continuos curves	Open curves, *smooth* direction change, continuos curves	*Preservation* of fringe direction, *non* continuos curves	Usually appear compined with other patterns, *variable* fringe density	*Abrupt* direction change from *one* direction to *another*, continuos curves
Possible cause	Internal detachment or void	Internal crack or detachment	Surface crack	Trends	Material change or surface

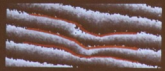
Field of view

Local vs overall ratio = percentage of anomalies used to priority maps and evaluation of deterioration

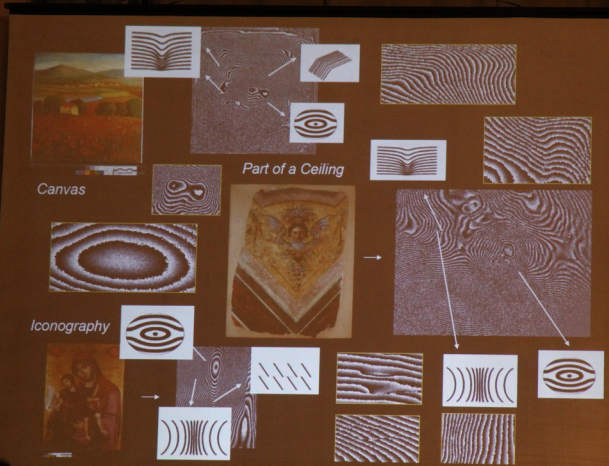
Where:

- **Overall patterns** refer to total field of view of the recorded surface geometry
- **Local pattern** refer to defect localisation in part of overall general

Dead end fringes suggesting surface crack



Curved fringes suggesting internal crack or detachment


Part of a Ceiling
Canvas
Iconography

Examples

Object: Front view (left), back view (right)

Not enough information about the origin

What we know:
- part of the decoration of a ceiling.
- the last layers of mortar have been detached
- fastened in linen cloth and a wooden frame.

Area of interest

Risk priority map

Examples

Camvas

"The small house in the country"

Deterioration of surface area
Deterioration of the middle layers
Deterioration of substrate area

Front view (left), Risk map (right)

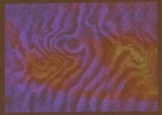
Area of interest

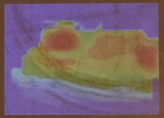
From 00;00;00,000
to
00;00;32,000 sec
[excitation: 1 sec, FB]

Portable Hybrid instrumentation

St Savin sur Gartempe

- UNESCO
  World heritage site
- 11th century mural paintings





Discussion

- Fringe patterns become **key-indicators** on art conservation and restoration planning
  - High resolution differentiate the depth and value of deformation
  - Provides **high resolution** information in **real time** with fast acquisition
  - Differentiates a deformation field crucial for conservation actions
  - Provides **detailed map** on subsurface defects
  - Provide information on possible evolution of cracks-detachments etc
- Ability of monitoring the surface deformation **due to environmental fluctuations**
  - Ability of scanning large areas as well as focusing on smaller ones
  - Targeted excitation with the use of several types of excitation
- Ability of examining several types of artworks (canvas, wooden panel paintings, wallpaintings, statues)
  - Quantitative **non destructive** documentation

Acknowledgments

Hellenic Institute of Holography

&

Taurus Ltd