Component characterization using optical methods

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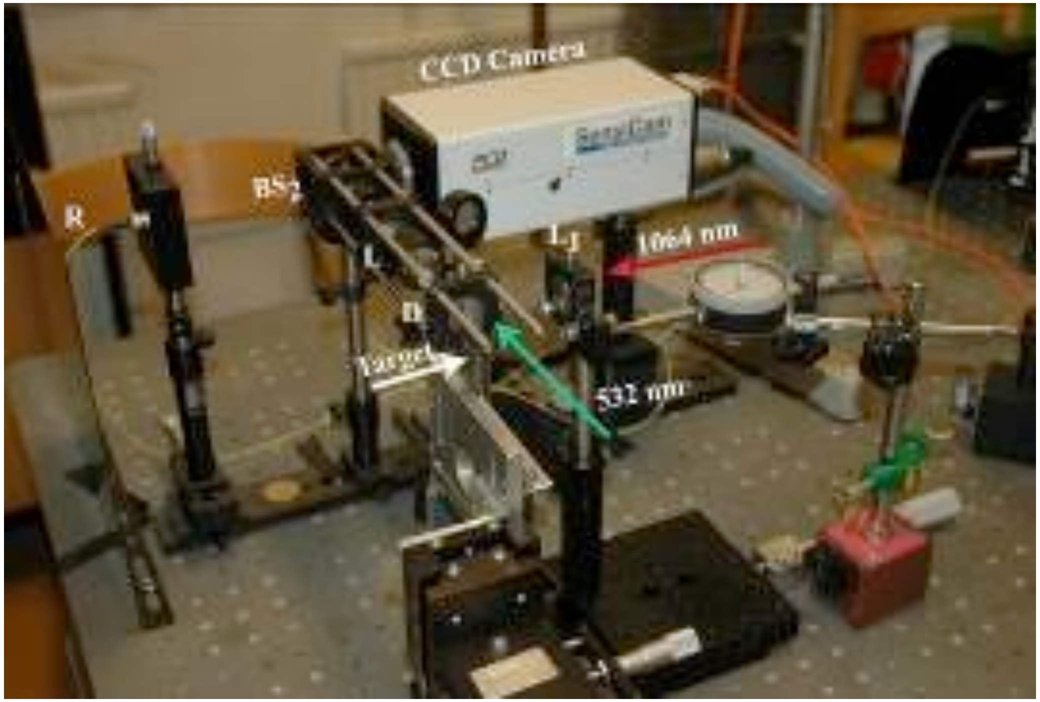
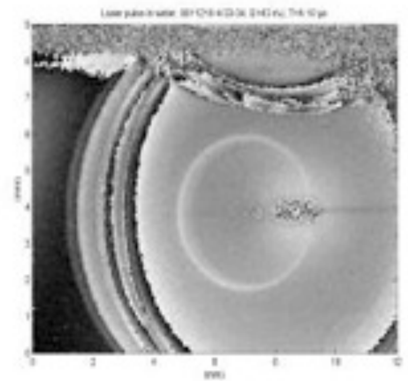
Shape
Defects
Mechanical response
...



Experimental methods

- Intensity based methods
- Imaging
- Image processing
- X-ray microtomography
- Interferometric methods
- Laser vibrometry
- Digital Holography
- Mixed domain imaging



Pulsed Digital Holography

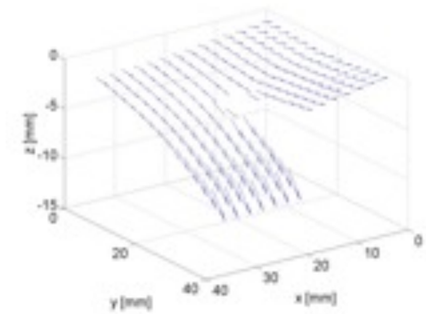
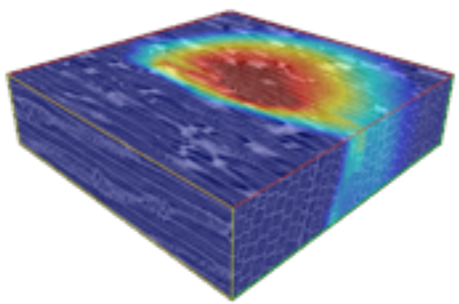


Image correlation



Volume correlation

High-speed photography

Sensing?

Understanding
(information processing)

Seeing
(stereoscopic imaging)

Smelling
(gas mass spectroscopy)

Hearing
(microphone)

Tasting
(liquid mass spectroscopy)

Sensing
(contact sensors)

Sensing?

Understanding
(information processing)

Seeing
(stereoscopic imaging)

I move,
therefore I see

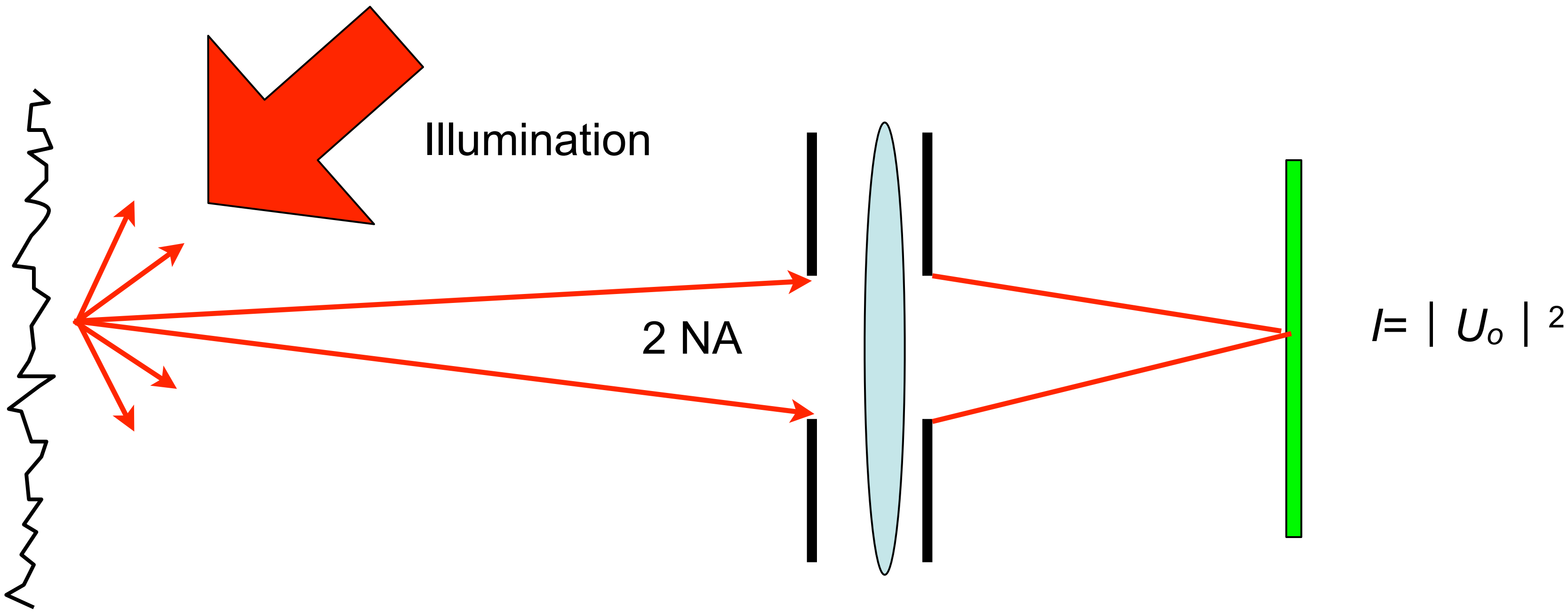
Smelling
(gas mass spectroscopy)

Hearing
(microphone)

Tasting
(liquid mass spectroscopy)

Sensing
(contact sensors)

Imaging (Intensity)



For most engineering materials mostly surface or close-to-surface properties

Measurement of shape

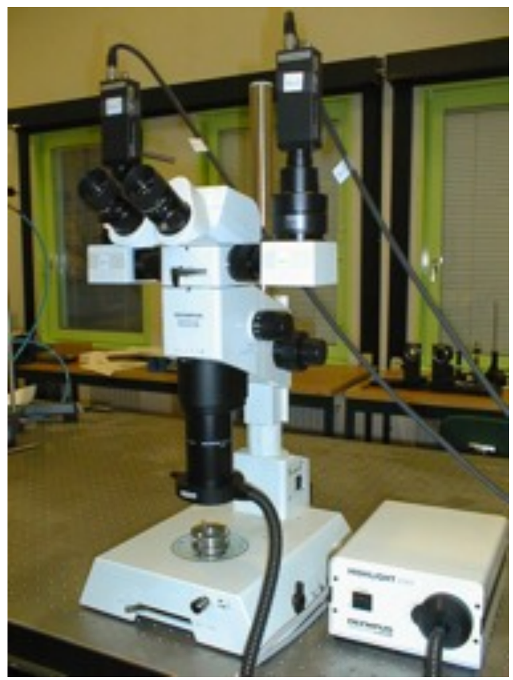
Method	Range	Accuracy	Speed
Defocus	< 10 m	~NA (1)	1-20 imag.
Stereo	< 5 m	~sinθ (0.1)	1 imag.
Fringes	< 5 m	~sinθ (0.1)	1-20 imag.
Plenoptic	< 10 m	~NA (1)	1 imag.
Phot. stereo	< 10 m	~qualitative	3-5 imag.
TOF	< 10 m	~Λ (1)	2 imag.
Holography	< 1m	~λ (10^{-3})	1-2 imag.

Stereoscopic surface shape and deformation

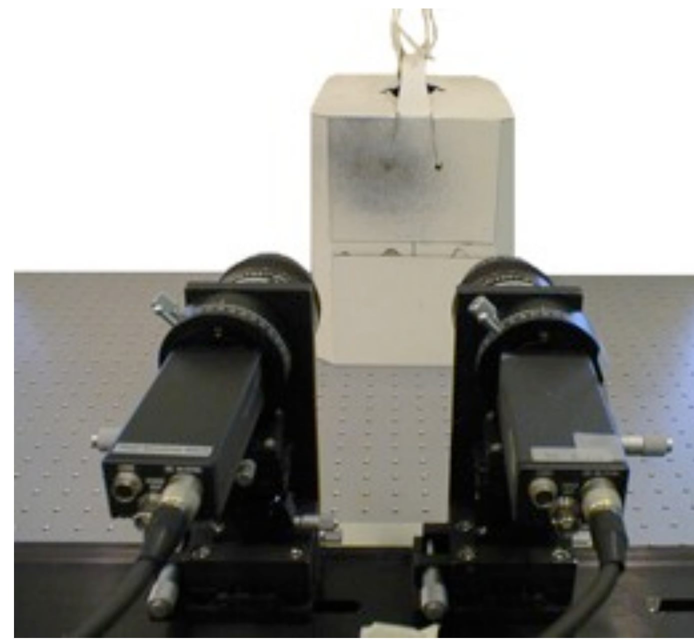
- Principle: emulates a large lens

When a deforming object is viewed from two different directions it is possible to measure both the shape and surface deformation of a deforming object simultaneously using stereovision provided the same features can be seen in both views

(a)

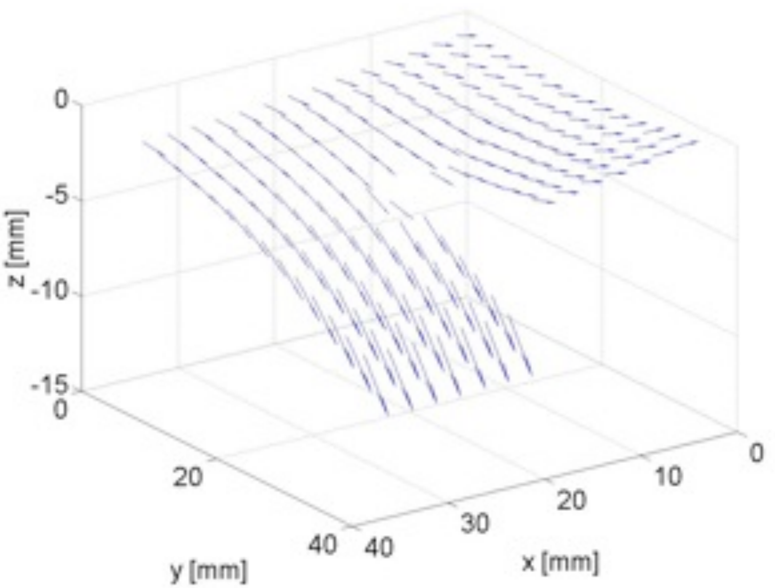


(b)

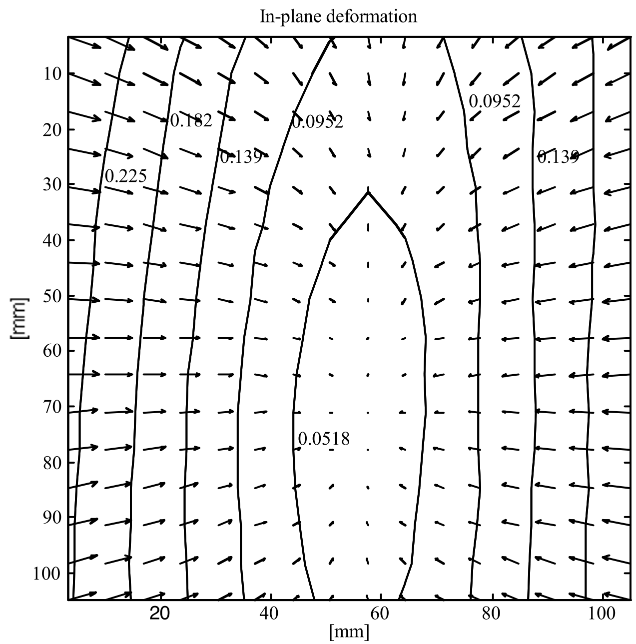


(a) Microscopic set-up
(b) Macroscopic set-up

Typical results

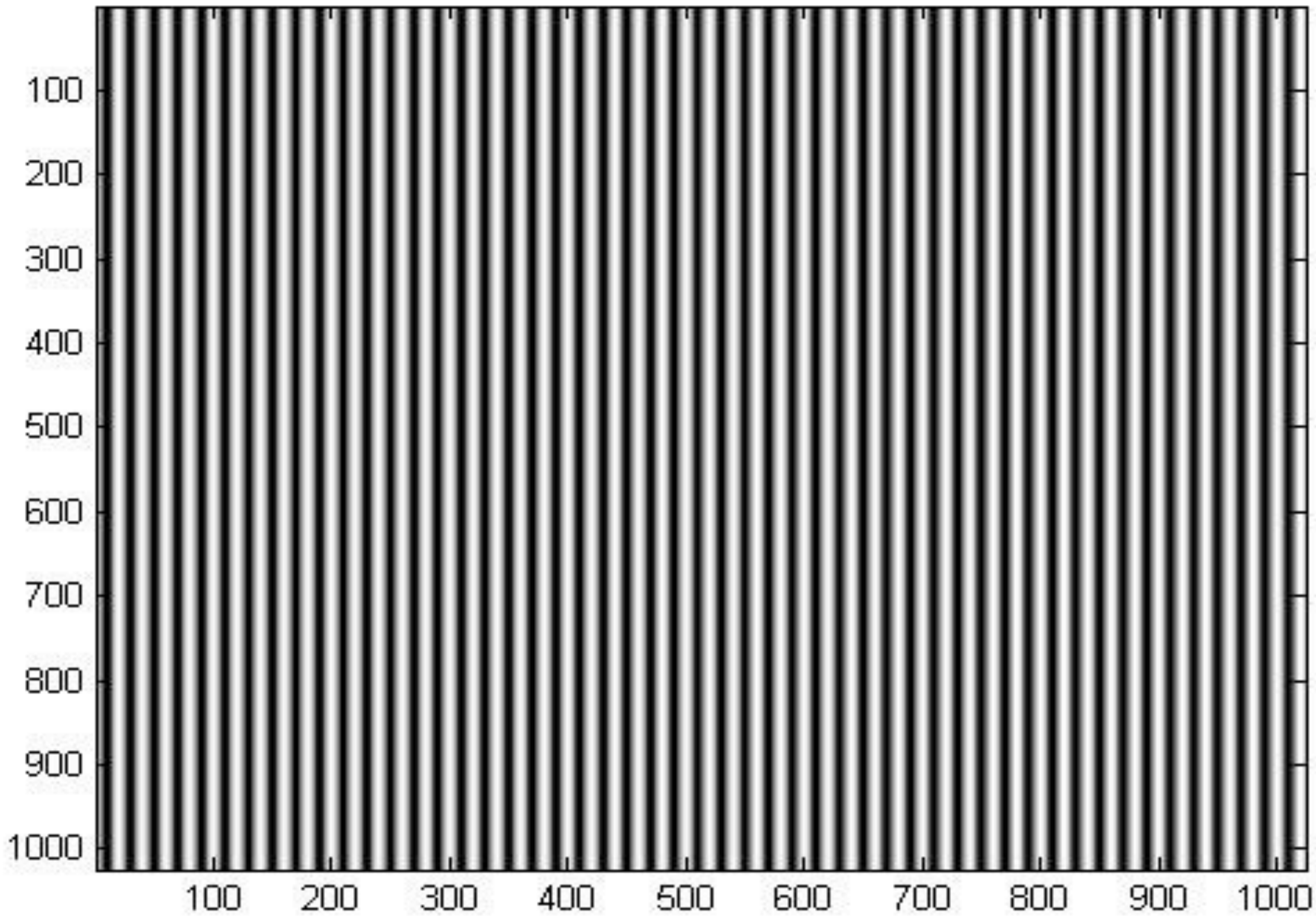


Deforming beer box around the handle

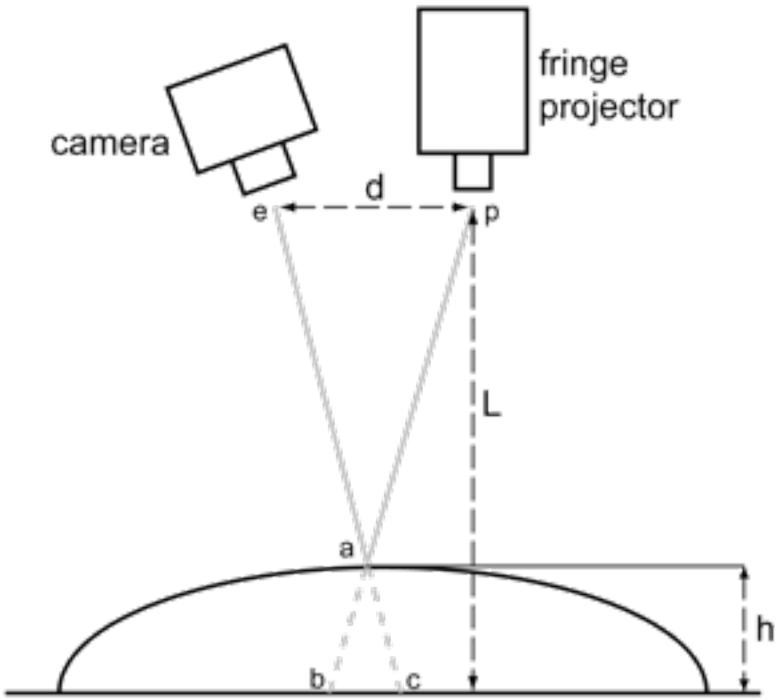


Hygroexpansion in copy paper

Projected fringes



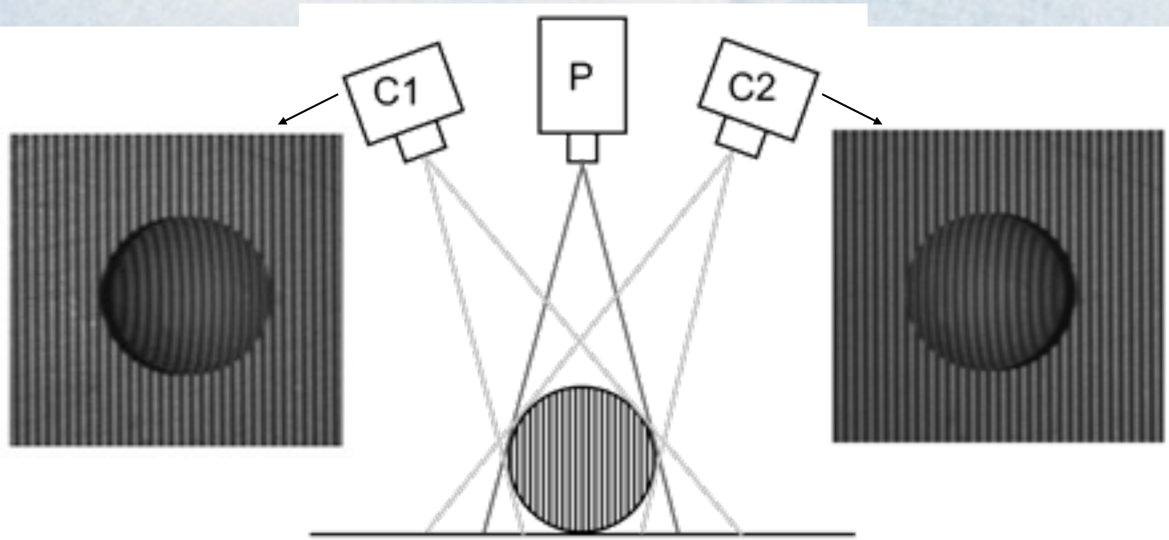
Typical implementation



Restrictions
- Typically 4 x 10 images are projected
- Sensitivity in x-z plane, less sensitive in y

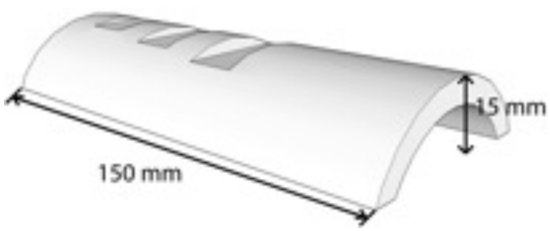
Commercial systems
- GOM
- Vialux
- Phase vision
- Breuckmann
- Dantec
- Steinbichler
- …

Possible to combine with stereovision
+ relationship with defocus obvious



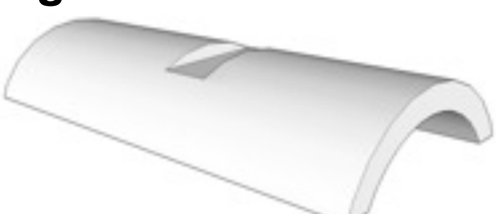
- Only one image recording
- Including information about the digital master

Measurement of object:

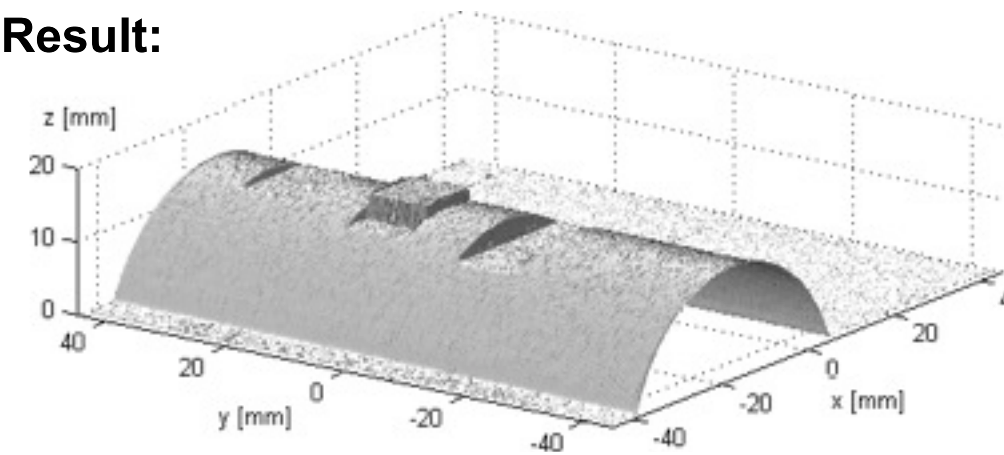


radius: 24 mm
traces: width 10 mm, depth 1,2 & 3 mm

Digital master:

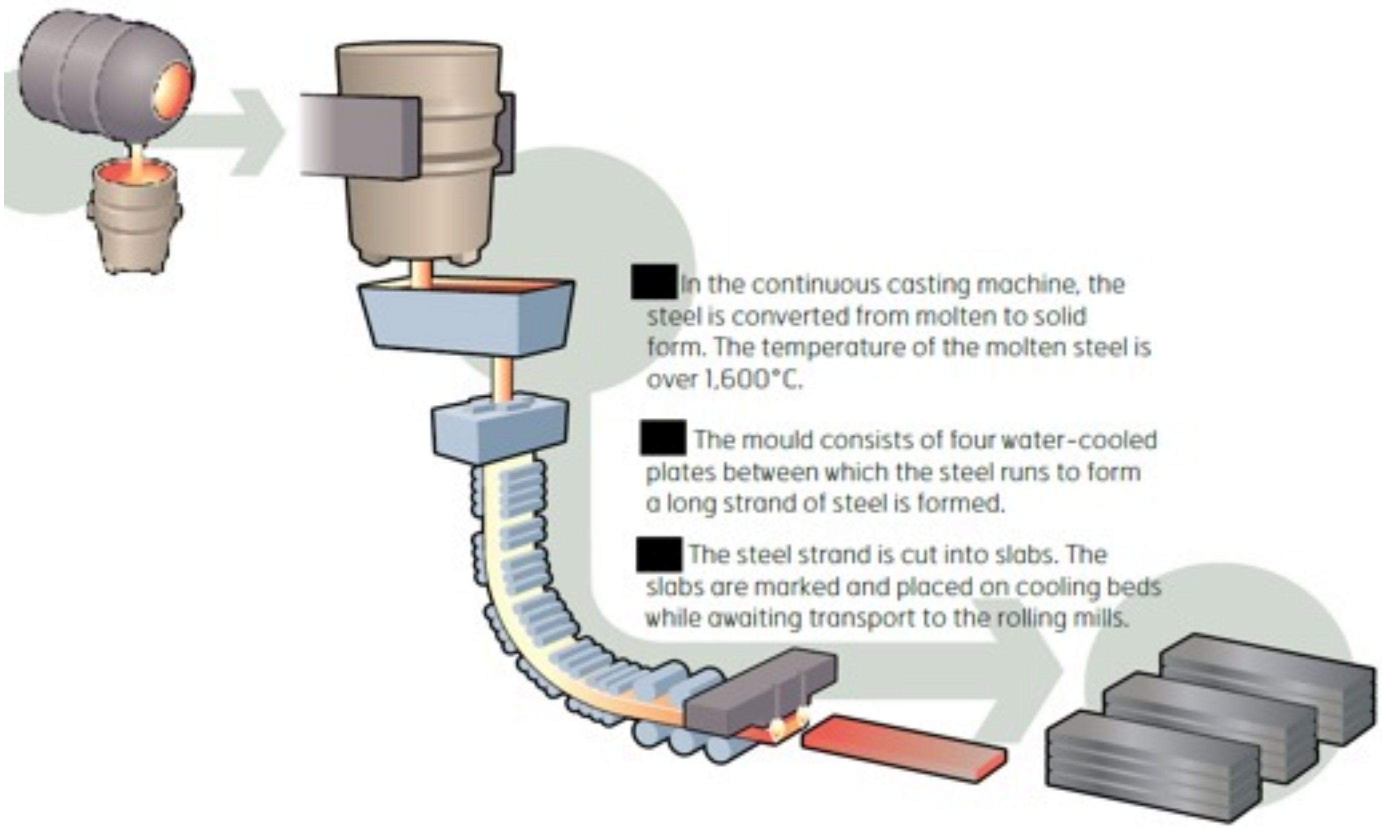


Result:

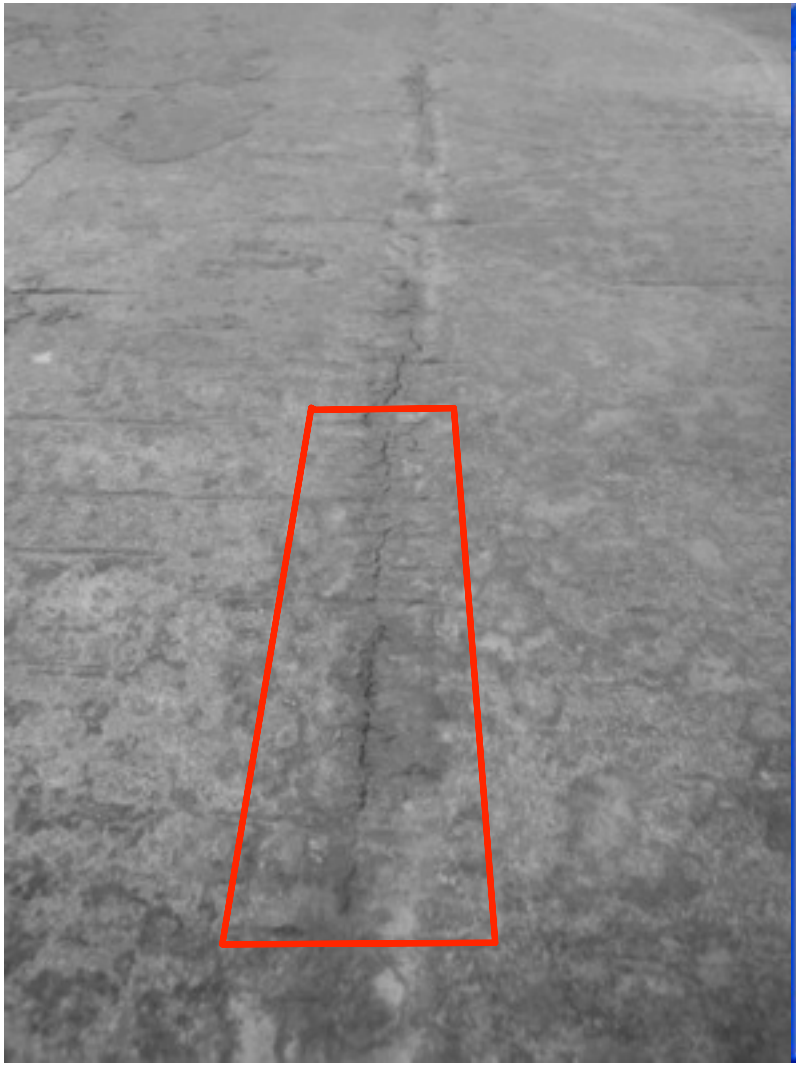


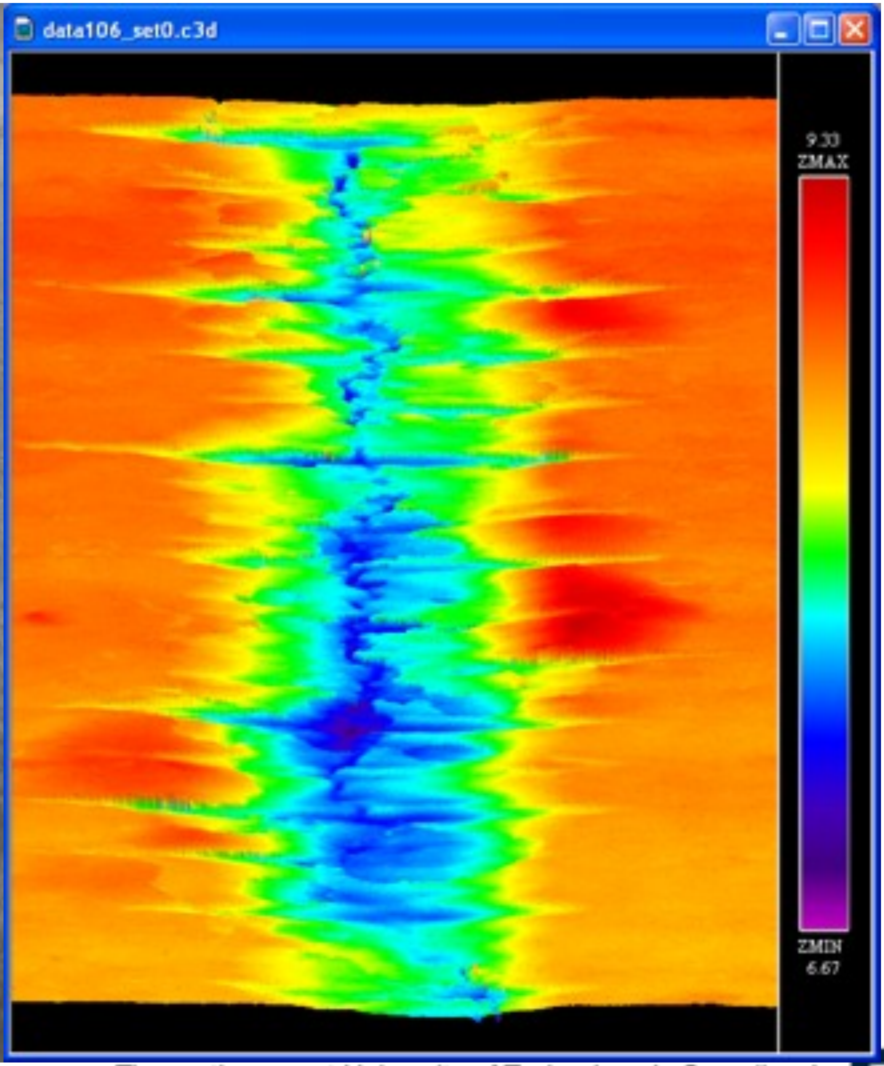
Accuracy ≈ 45 µm
Largest allowed deviation ≈ 1.6 mm

Industrial example with a projected line (rather than fringes)



Laser Triangulation – 3D Data with Cracks



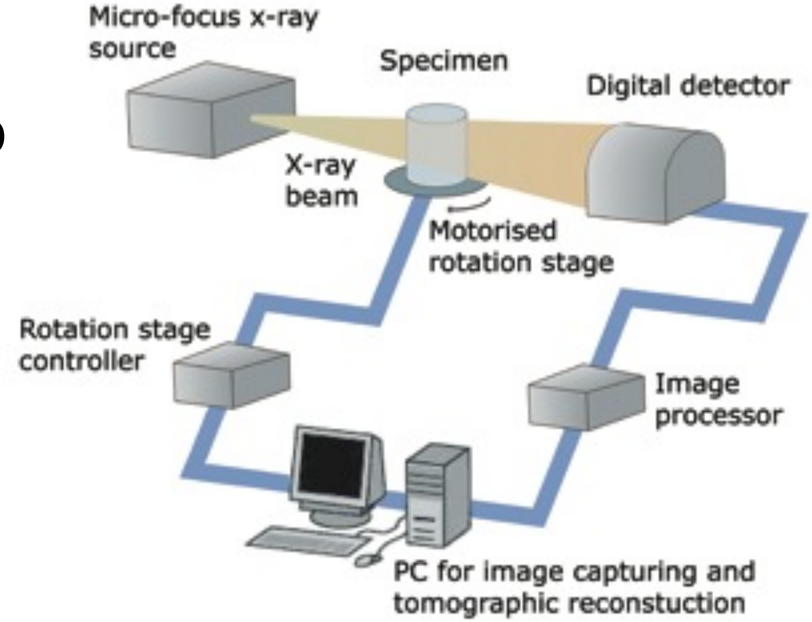


3D imaging and deformation analysis using x-ray microtomography

3D imaging

Development and application of methods for 3D imaging and quantitative analysis of internal deformation and strain in inhomogeneous materials.

The investigated material is imaged in 3D using x-ray microtomography.

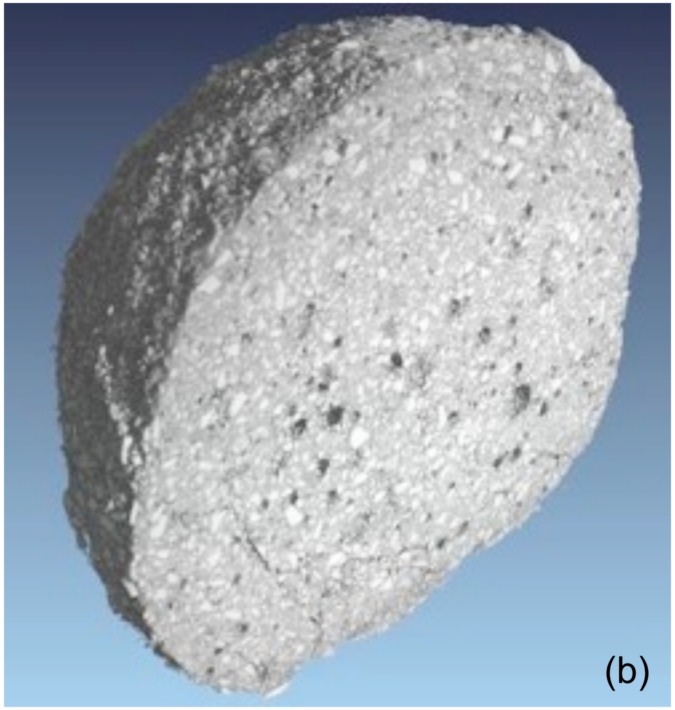


3D imaging

Here, a dried iron ore pellet (a), 4.5 mm in diameter, was scanned with microtomography.

The result (b) is a high resolution 3D image that describe the microstructure (density variations) throughout the material.


(a)


(b)

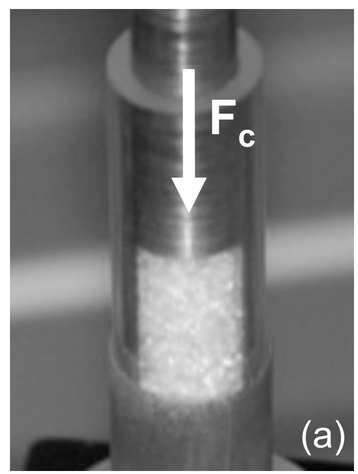
3D imaging and deformation analysis

From two scans with microtomography, separated in time, it is possible to determine the size of an intermediate structural deformation of the material.

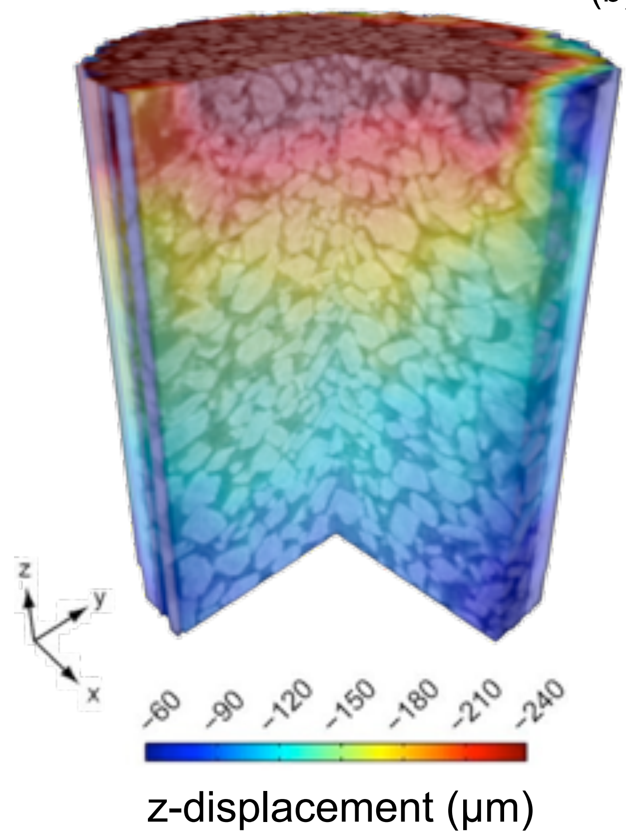
Use [u,v,w] as unknowns which gives a technique known as Digital Volume Correlation (DVC)

Here, a cylindrical bed of granular sugar (a), 7 mm in diameter, was exposed to compression.

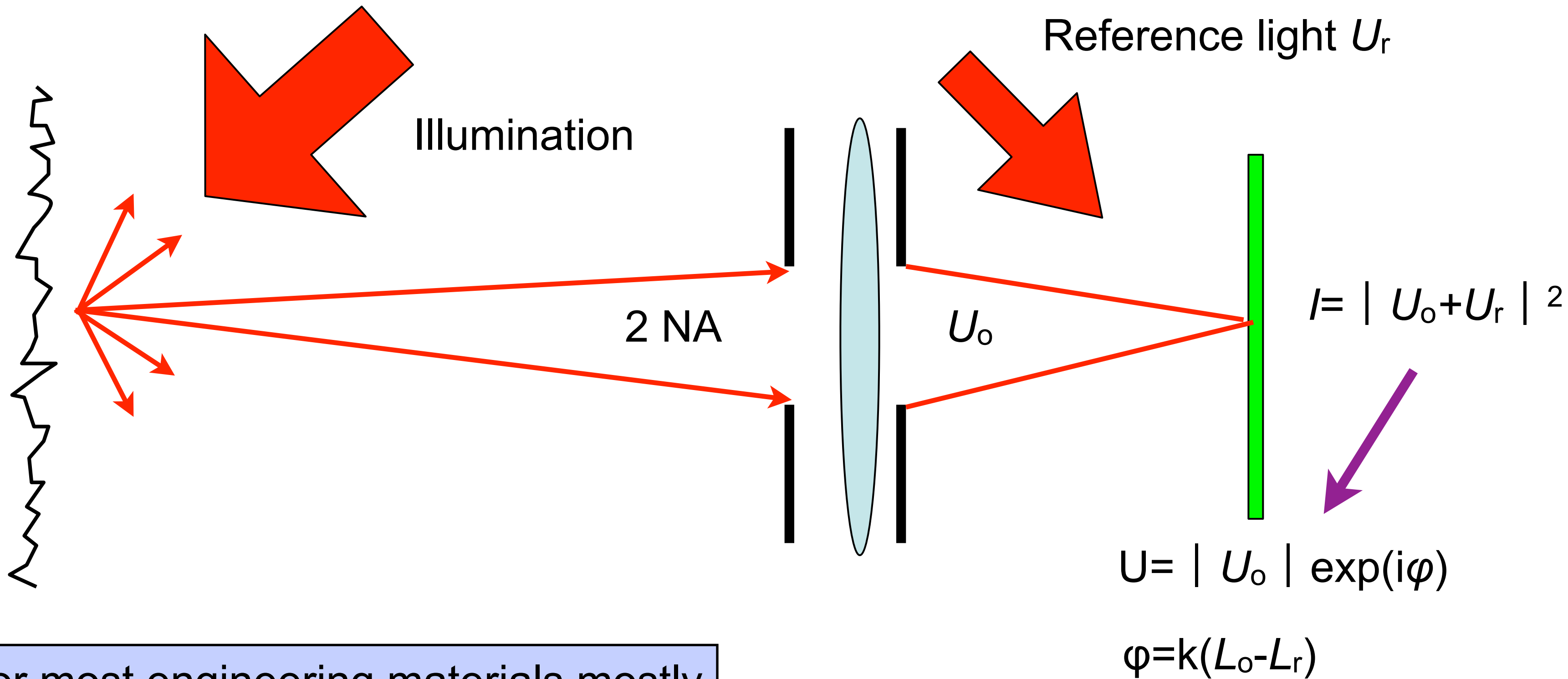
The result (b), after analysis with DVC, is a 3D deformation field that describe the compaction inside the granular material (in µm), due to the compressive load.



(b)

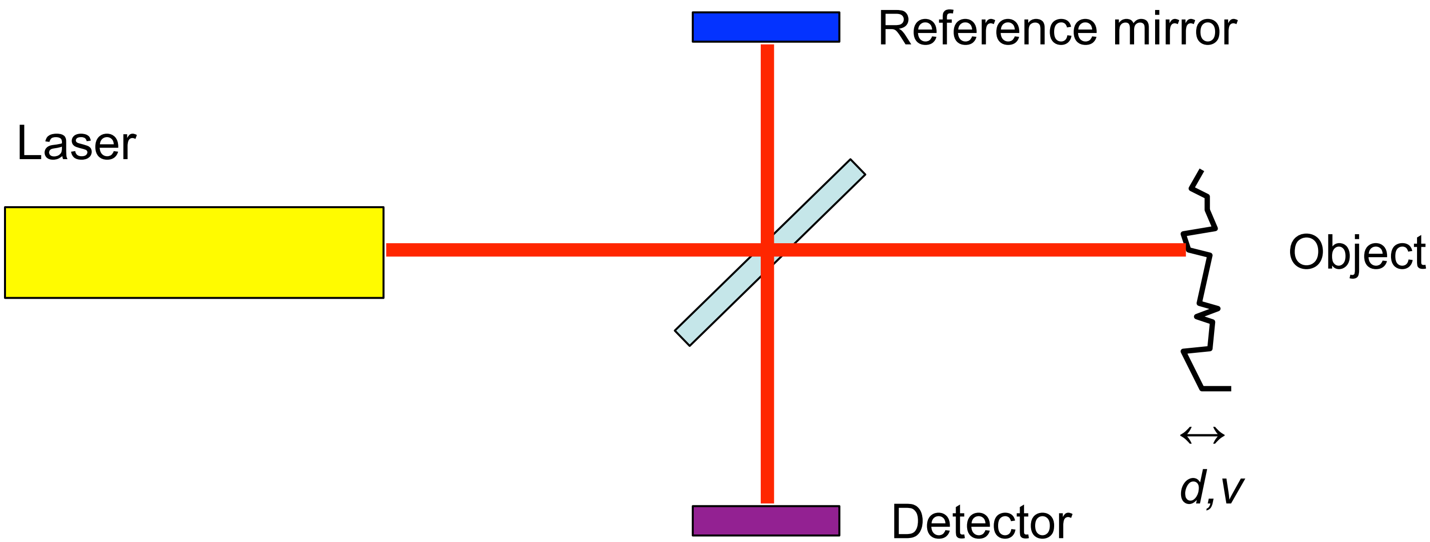


Interferometric techniques (Laser)



For most engineering materials mostly surface or close-to-surface properties

Classical examples (Michelson)

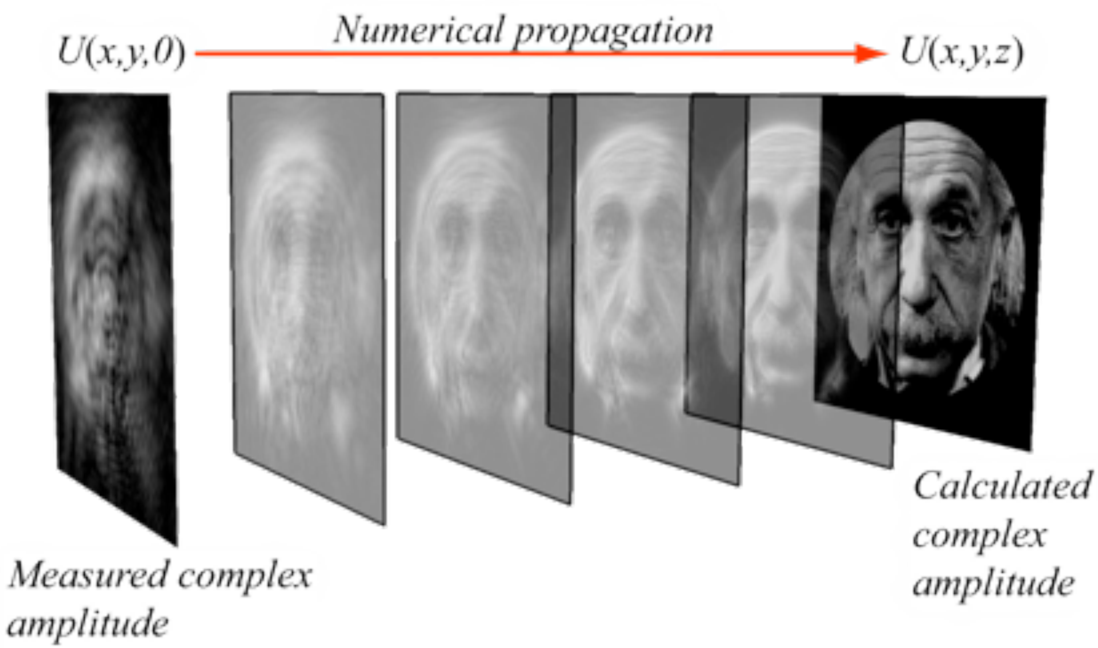


Deformation: $2kd \rightarrow d \sim 1$ nm
Doppler shift: $f_0=2kv \rightarrow v \sim 1$ μm/s
$k=2\pi/\lambda$

Digital holographic reconstructions

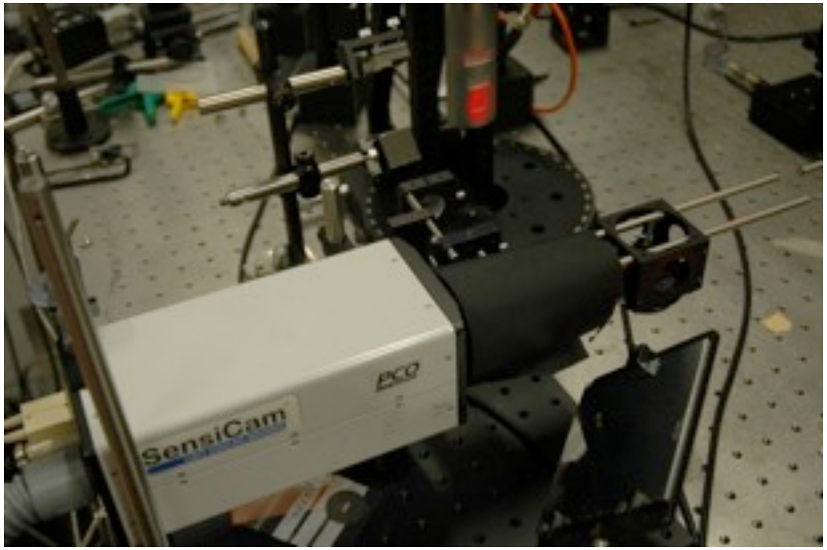
$$U(x,y,z) = \iint \Im\{U(x,y,0)\}\exp[ikmz]\exp[ik(px+qy)]dpdq$$

$\Im$ denotes a Fourier transform, $p^2+q^2+m^2=1$

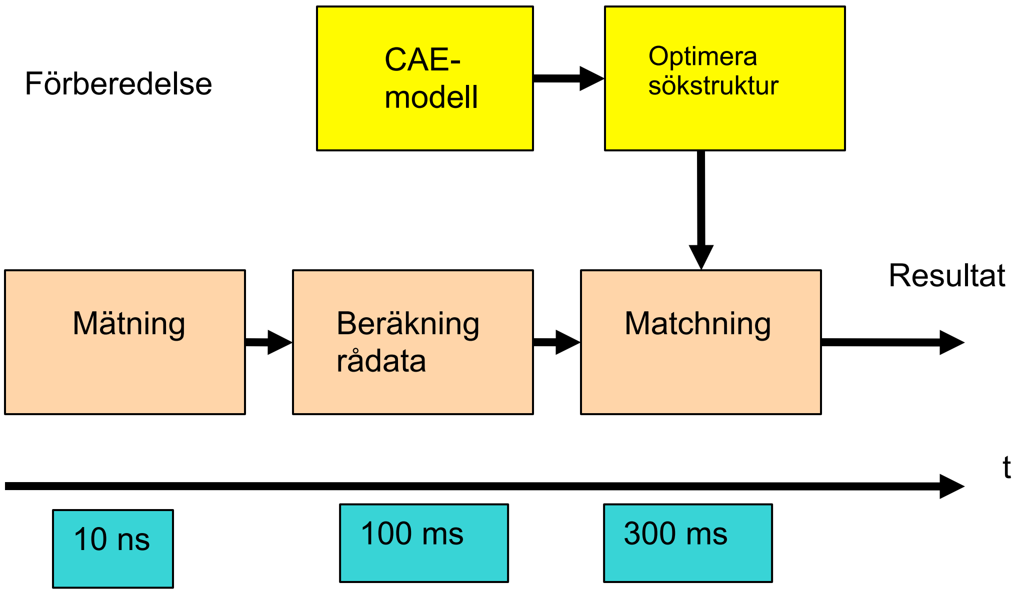


Holographic shape control

- **Objective:** To control the shape of a manufactured component on-line in the production.
- **Concept:** Pulsed multi-wavelength Digital Holography and numerical point-cloud matching.
- **Here:** The manufactured component is seen illuminated in the upper part of the image whereas the detection part of the system is seen in front.

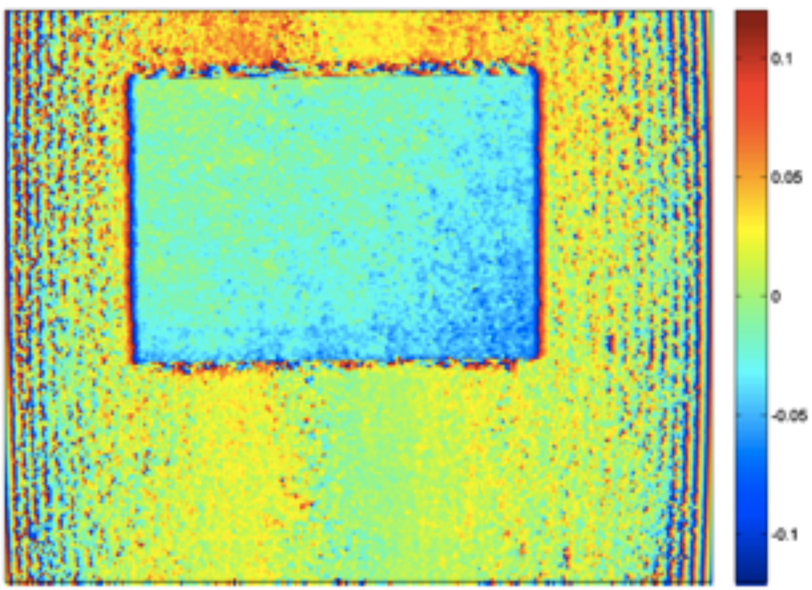


The strategy (in this case geometric data)

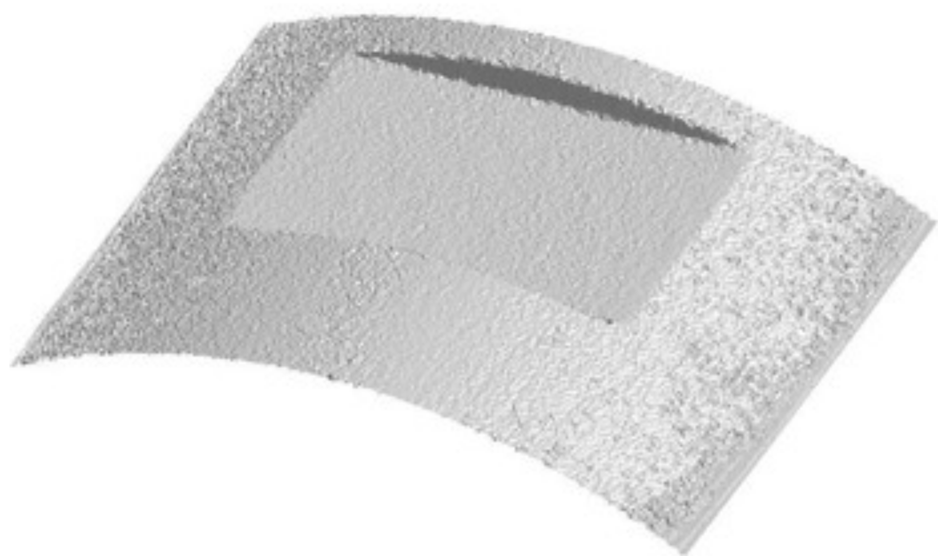


The object

A result using two wavelengths

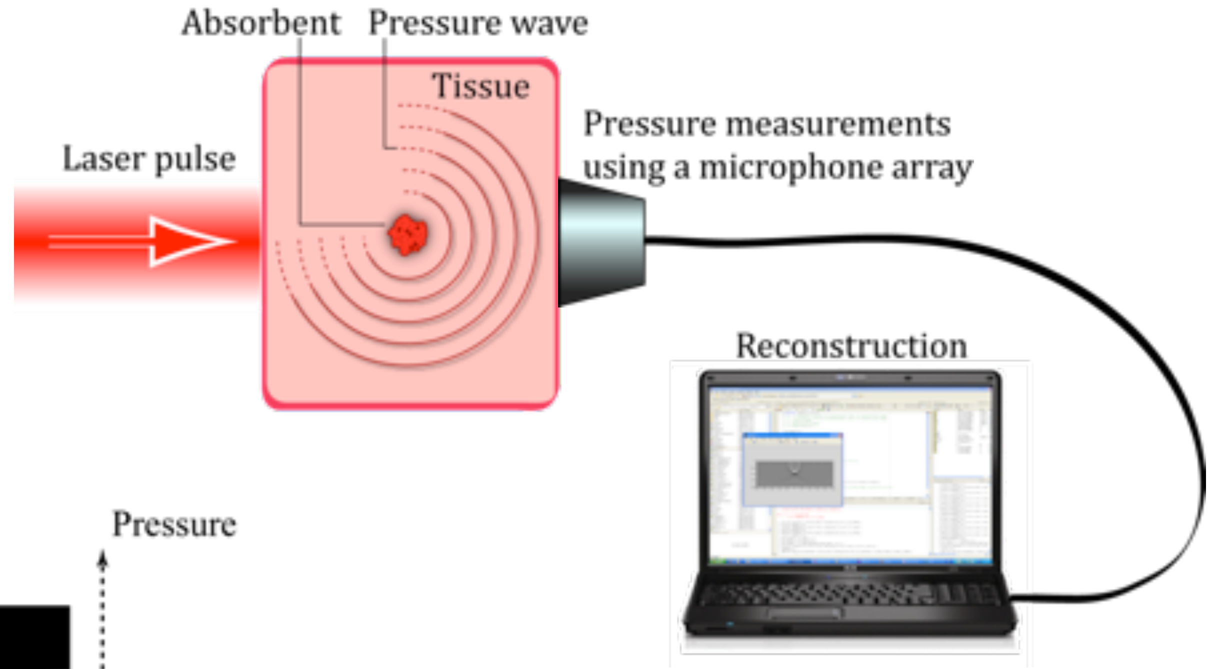


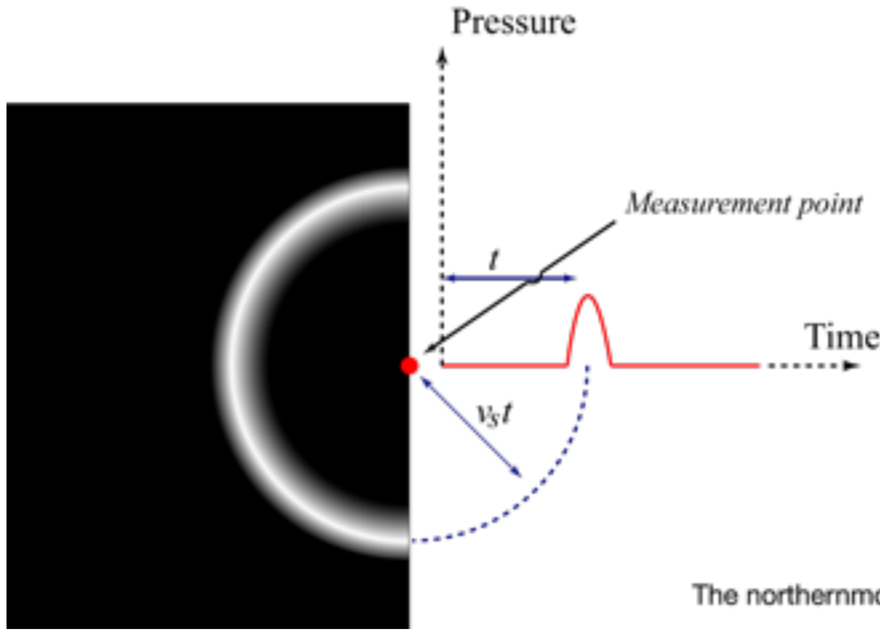
Residual image between model and measurement



Final shape of the object

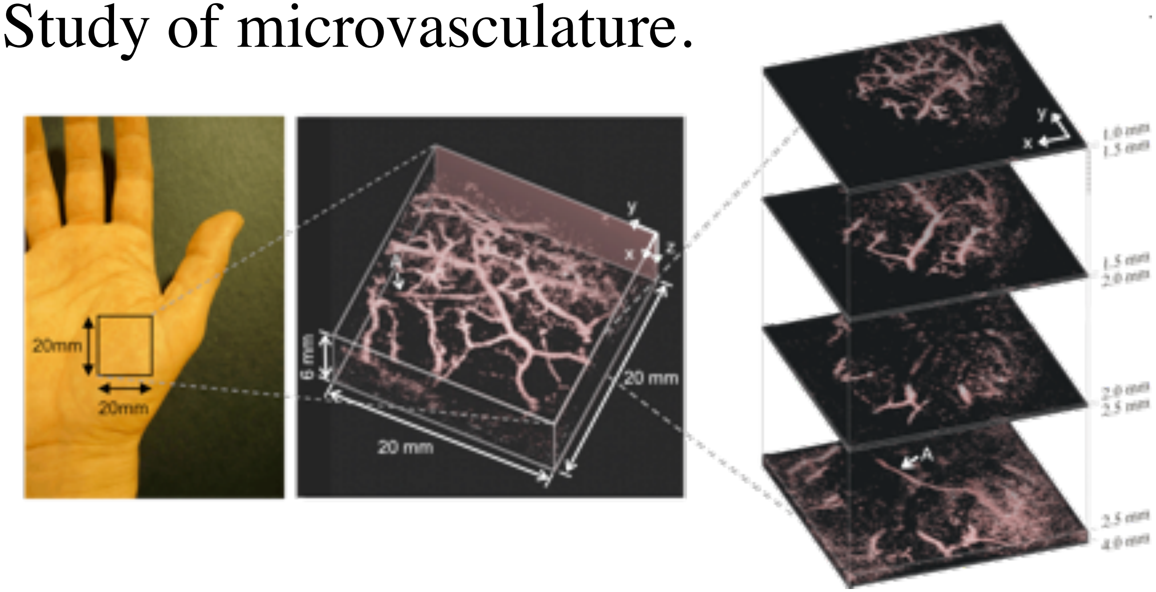
Mixed domain methods
Sound - light


Absorbent
Pressure wave
Tissue
Laser pulse
Pressure measurements
using a microphone array
Reconstruction


Pressure
Measurement point
t
Time
$v_s t$

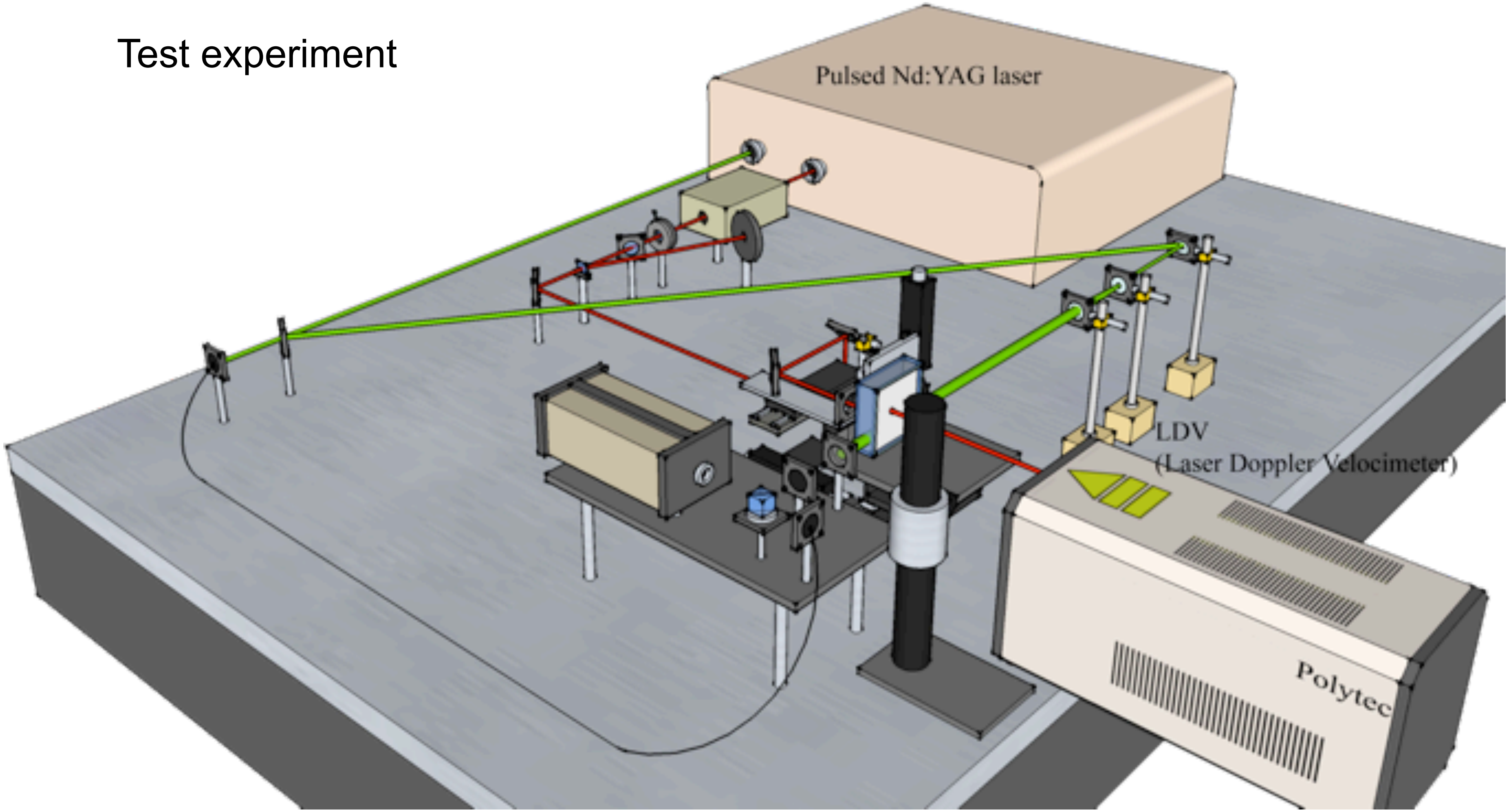
Imaging of blood *in vivo :*

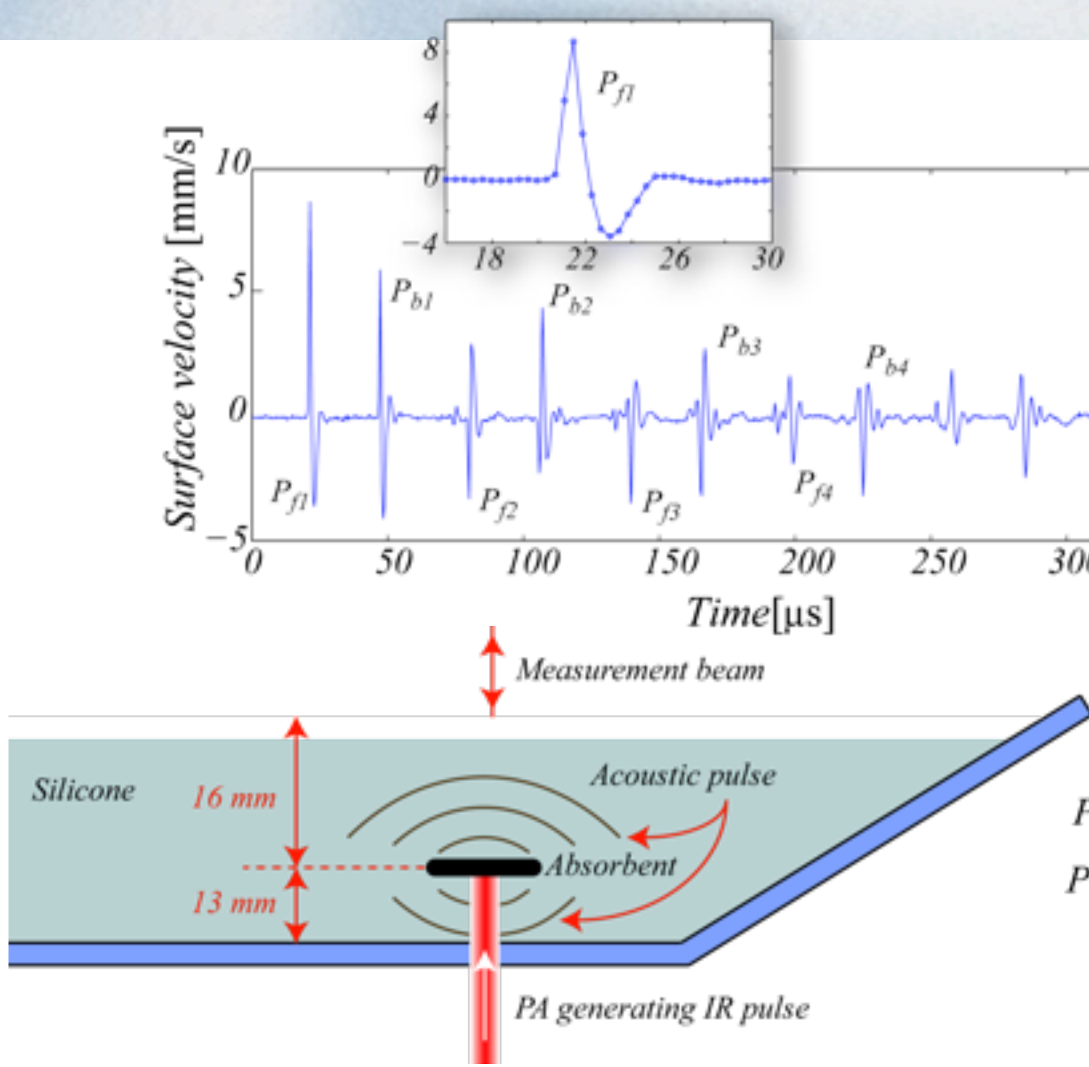
- Early detection of tumors.
- Quantitative determination of blood oxygenation and flow velocity.
- Study of microvasculature.



Picture borrowed from UCL Centre for Advanced Biomedical Imaging.

Test experiment





P_{f1}: Absorbent → surface 16 mm

P_{b1}: Absorbent → bottom → surface 42 mm

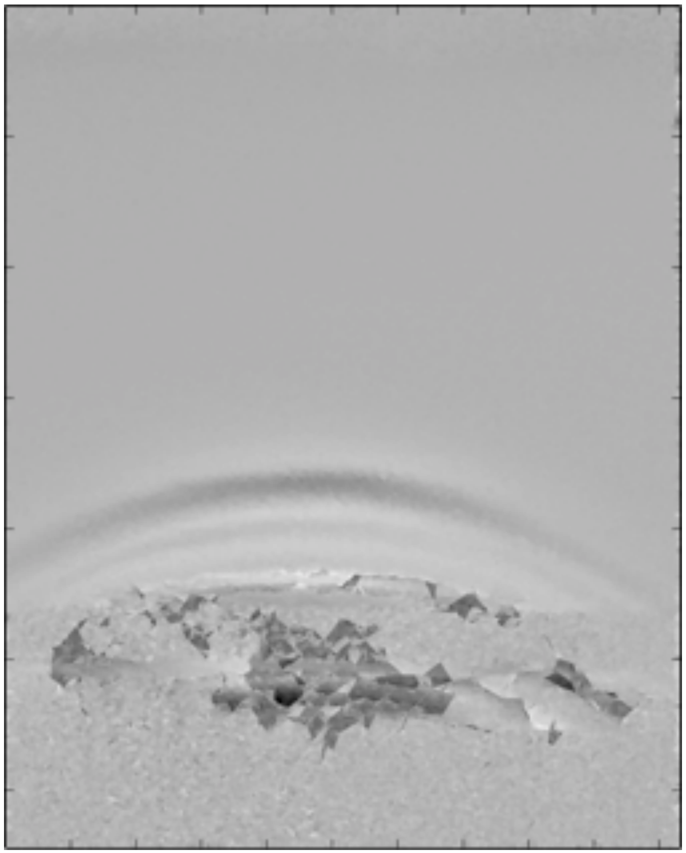
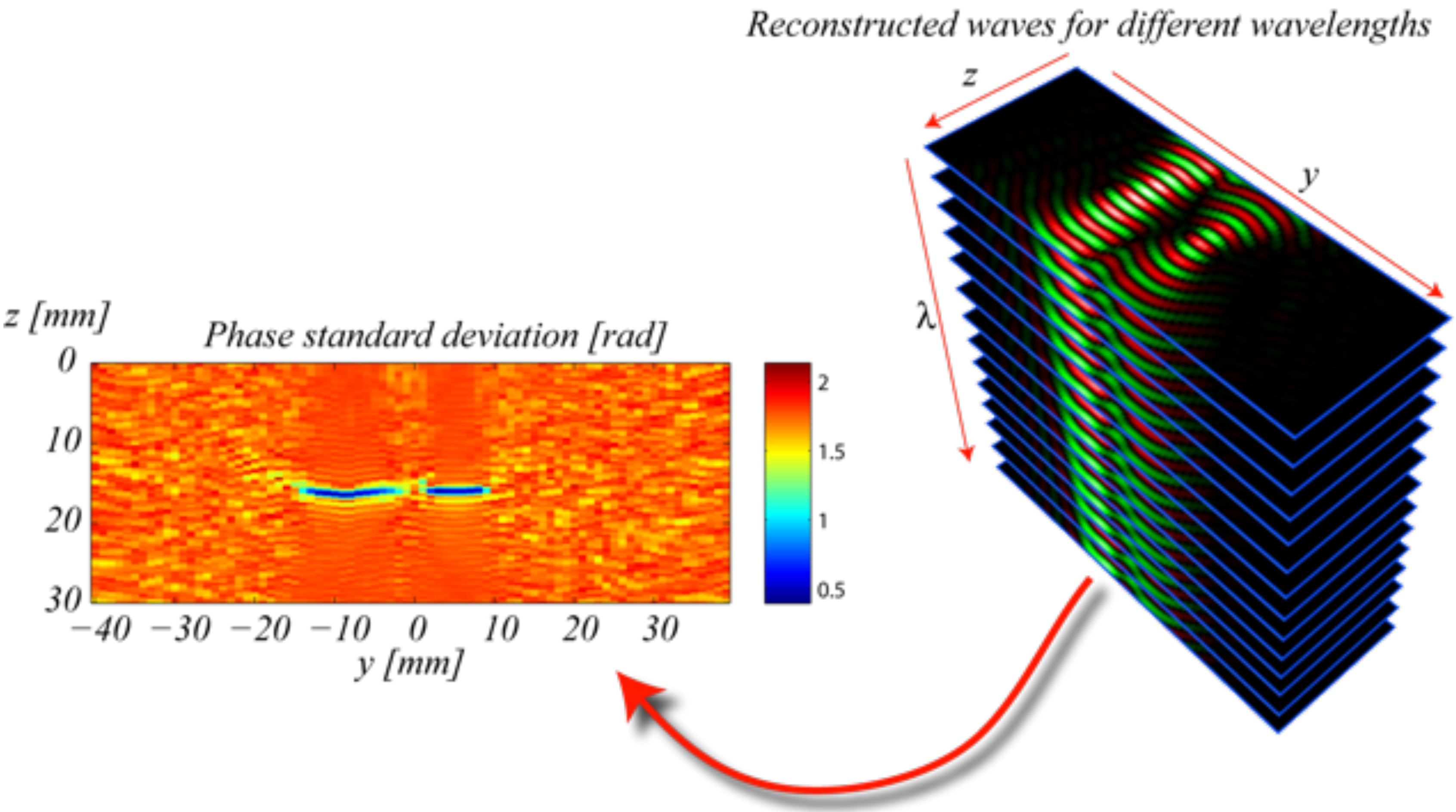


Image size = 10 x 12.5mm^2.

Image taken 5μs after excitation.


Reconstructed waves for different wavelengths
z
y
λ
z [mm]
Phase standard deviation [rad]
0
10
20
30
−40 −30 −20 −10 0 10 20 30
y [mm]
2
1.5
1
0.5

Conclusions

- Optics is great for imaging.
- Hardware is relatively cheap for high resolution.
- The wavelength of light ~0.5 μm makes it an accurate ruler for small changes.
- Mixed domain methods are an attractive alternative if features are invisible.