FWI for Ultrasonic Imaging

Flaw detection in steel weld

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Université du Maine

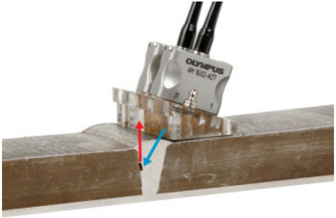
cnrs dépasser les frontières

ISTerre
Institut des Sciences de la Terre

NDT for welds

Picture from Davidmack

Pipeline test



Picture from Olympus

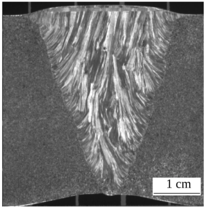
Echo mode testing

Non destructive testing for weld in :

- nuclear reactors (cooling system)
- oil and gaz pipelines

→ porosity, cracks, lack of fusion, corrosion, inclusions,. . .

NDT for welds



Picture from Chassignole, 2010 (PhD thesis)

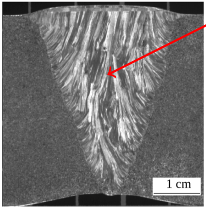
Macrography of a weld

- delay and sum methods
- decomposition of covariance matrix (DORT)

NDT for welds

Strong unknown anisotropy

$\hookrightarrow$ distorsion and splitting of the beam



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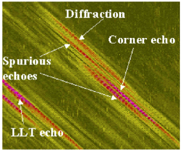

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Comparison of ray based model and experiment result

- delay and sum methods
- decomposition of covariance matrix (DORT)

→

✗ need to know c a priori

✗ strong artefacts

NDT for welds

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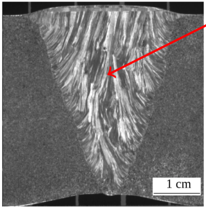

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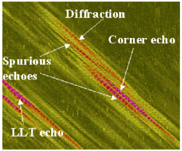

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Comparison of ray based model and experiment result

- delay and sum methods
- decomposition of covariance matrix (DORT)

→

✗ need to know c a priori

✗ strong artefacts

- solving NL optimization problem

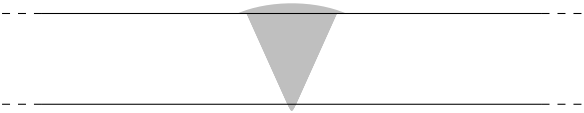
→

▶ contour reconstruction : *Dominguez et al.*, *Rodriguez et al.*

✓ C_{ij} reconstruction : FWI

What is specific to weld imaging ?

- 2 free surfaces : more information $\leftrightarrow$ non-linear inversion



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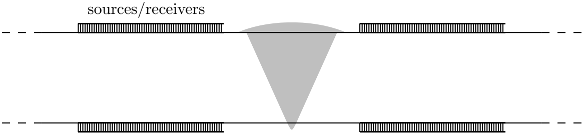
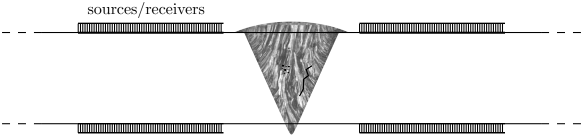


What is specific to weld imaging ?

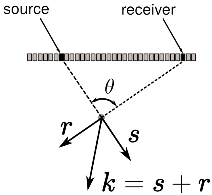
- 2 free surfaces : more information $\leftrightarrow$ non-linear inversion
- surface acquisition only
- anisotropy $\rightarrow$ multi-parameter inversion
  ($C_{ij}\times 6$: weld + defects)



Resolution analysis

$$\frac{\partial C}{\partial m_i} = \underbrace{{}^t\tilde{\boldsymbol{d}}_{cal}}_{\text{incident wavefield}} {}^t\left(\frac{\partial \boldsymbol{A}}{\partial m_i}\right) \underbrace{\boldsymbol{\lambda}}_{\text{back-propagated residual wavefields}}$$

$$\sim \Re\left(e^{jk_0 \boldsymbol{s}.\boldsymbol{x}}\right) \qquad \sim \Re\left(e^{jk_0 \boldsymbol{r}.\boldsymbol{x}}\right)$$



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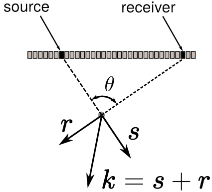
- Gradient resolution :

$$k = |\boldsymbol{s}+\boldsymbol{r}| = \frac{\omega}{c} 2\cos\left(\frac{\theta}{2}\right) \tag{1}$$

$$\tag{2}$$



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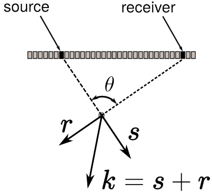
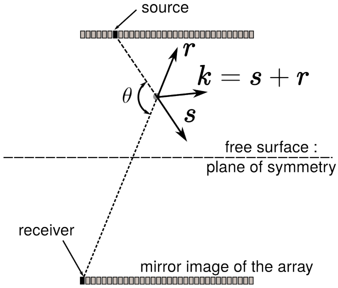
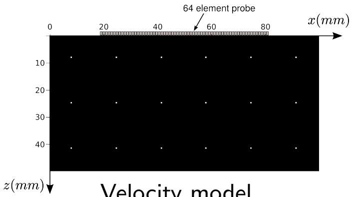
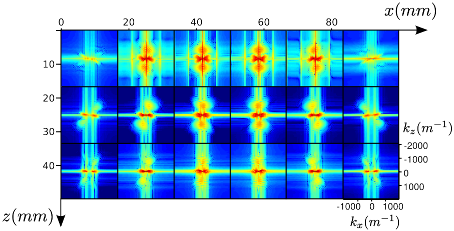




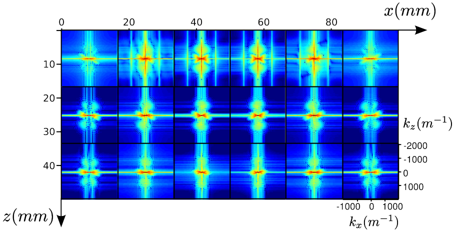
Resolution analysis – Local 2DFT



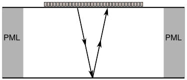
Velocity model

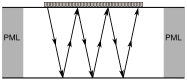


For 1 reflection



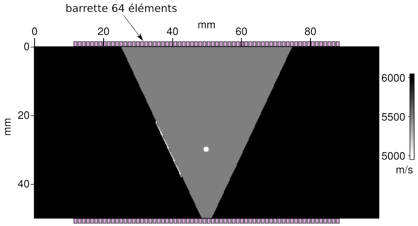
For 5 reflections



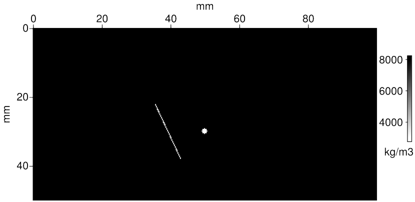


Isotropic Synthetic case

- 2D, isotropic, acoustic (*TOYxDAC_TIME_V1.5*)
- Parametrisation : v_p and ρ
- Recording time : 1 reflexion



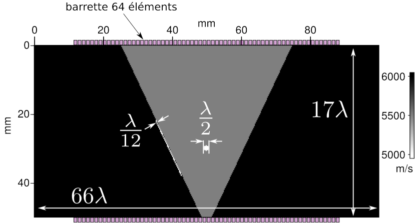
True velocity



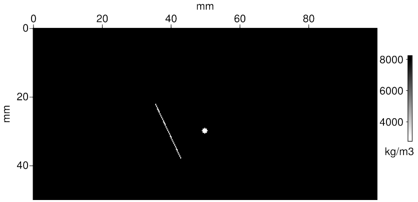
True density

Isotropic Synthetic case

- 2D, isotropic, acoustic (*TOYxDAC_TIME_V1.5*)
- Parametrisation : v_p and ρ
- Recording time : 1 reflexion
- Excitation frequency : 2 MHz



True velocity

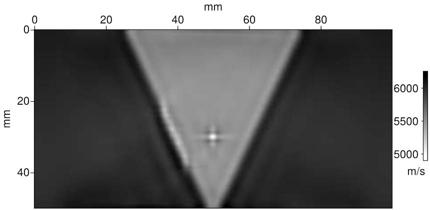


True density

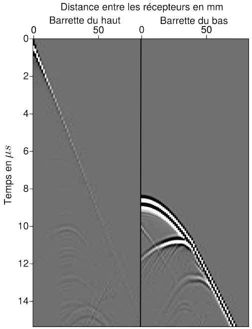
Transitional model

Building of a smooth velocy model :

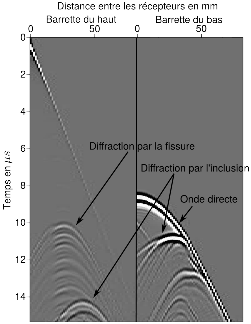
- from 200 kHz to 1 MHz
- strong smoothing of $\boldsymbol{\Delta m}$: Gaussian on 2 wavelengths



Smooth velocity model



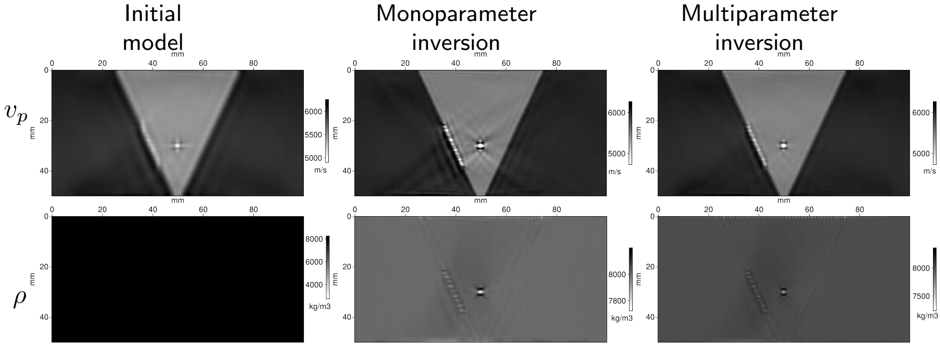
Homogeneous density



True density

Isotropic case

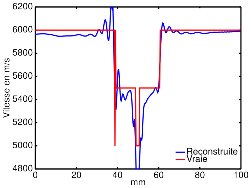
- 9 succesive inversions from 200 kHz to 3 MHz



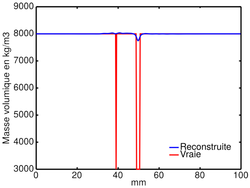
Isotropic case

- Monoparamter inversion :

velocity

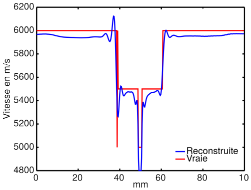


density

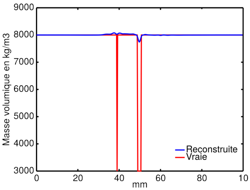


- Multiparameter inversion :

velocity



density

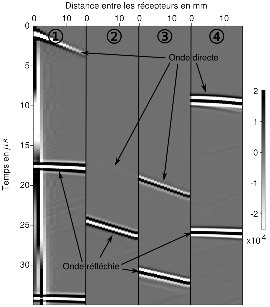


Horizontal profiles at 3 cm depth

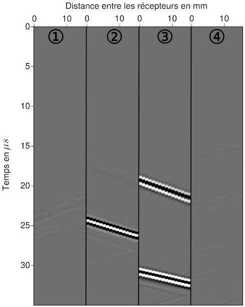
HTI case

- Acoustic approximation, transverse isotropic, horizontal symmetry axis
- Anisotropy parameters :

$$\epsilon = \frac{\boldsymbol{v}_p.\boldsymbol{e}_x - \boldsymbol{v}_p.\boldsymbol{e}_z}{\boldsymbol{v}_p.\boldsymbol{e}_z}$$

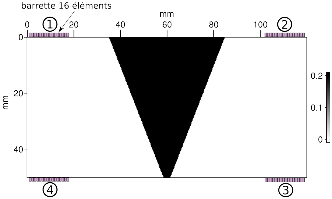


Data from true model

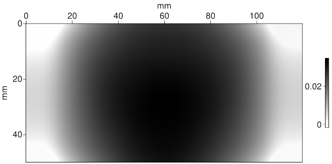


Initial residual data

True ϵ :



Reconstructed ϵ :



- Get info from horizontal rays : $\theta \sim \pi \quad \rightarrow \quad k \sim 0$
- Not realistic model

Conclusions

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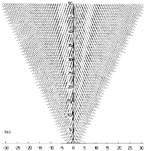
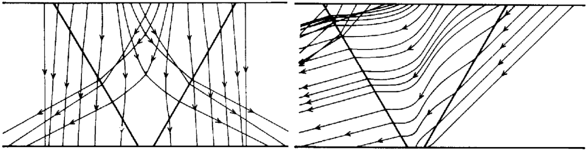
- Anisotropy model :
  - acoustic case : tilted transverse isotropic medium
  - elastic case : $6 \times C_{ij}$





Pictures from Ogilvy, 1986

(a) Grain orientation

(b) Ray tracing (compressional wave)

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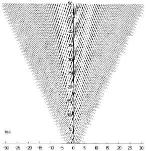

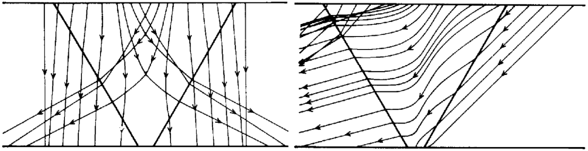

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(a) Grain orientation (b) Ray tracing (compressional wave)

- Building another initial model

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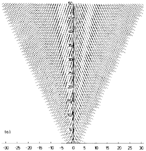

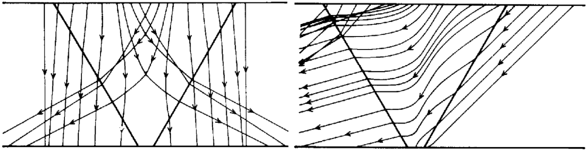

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- Building another initial model
- Real data application : 3D case

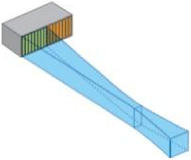

Image Olympus

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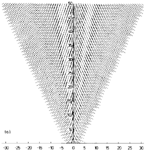
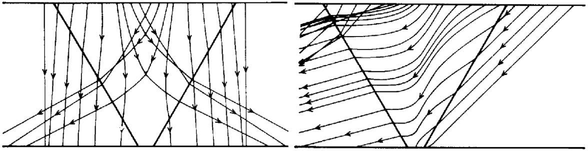
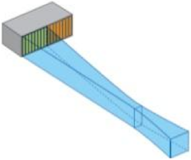




Pictures from Ogilvy, 1986

(a) Grain orientation (b) Ray tracing (compressional wave)

- Building another initial model
- Real data application : 3D case
- Real acquisition geometry
  - curvature at the top/root of welds
  - optimial illumination/resolution



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