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Interactive ultrasonic field simulation for nondestructive testing — Source link

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Topics: Software and Nondestructive testing

INTERACTIVE ULTRASONIC FIELD SIMULATION FOR NON-DESTRUCTIVE TESTING

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Context

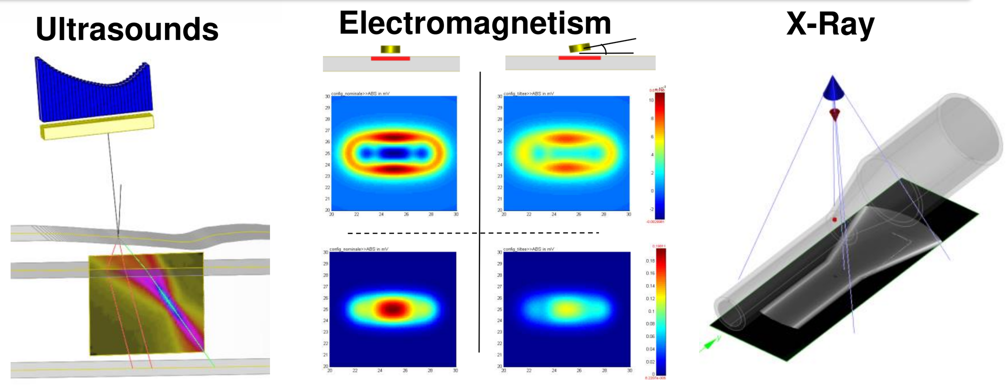
Non Destructive Testing (NDT)

Non-invasive techniques used for the detection of critical defects in parts or industrial structures

- Examinations are performed during manufacturing, in maintenance or in-service.
- Many industries: energy, petrochemical, aeronautics, transports, etc.
- Strong economic and public safety issues implied.
- Multiple techniques are used: ultrasounds, Eddy currents, radiography X or g, etc.

CIVA software

- **NDT Simulation and Analysis Platform**
  - Design of new methods/probes
  - Qualifications of methods
  - Interpretation of complex results
  - Virtual Testing at designing of parts
  - Training
- 200 customers, world-wide commercial distribution many contexts and use cases.



Need for interactive simulations

Ultrasonic Field Simulation

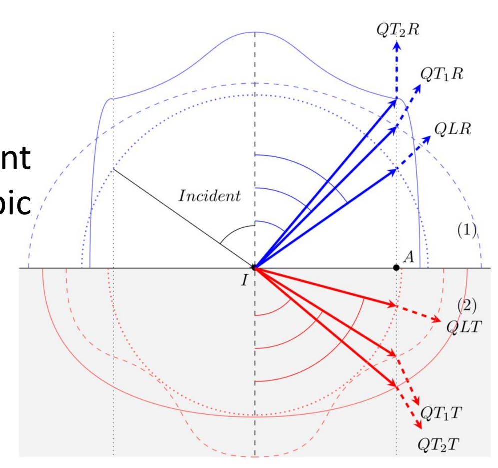
Ultrasonics Wave propagation

- Propagating in materials that can be :
  - Homogeneous or heterogeneous,
  - Solid or liquid, isotropic or anisotropic.
- Can interact with interfaces with :
  - Specular reflexions,
  - Refractions,
  - Possibly diffraction on edges.
- Two main types of volume waves in isotropic materials :
  - Longitudinal (compression waves) = L mode,
  - Transversal (shearing waves) = T mode.
- At any interface, mode conversions (from L to T or from T to L) can happen.
- Boundary representations for pieces.
- Probes : US waves emitters/receivers, mono-element or phased array.

Anisotropy

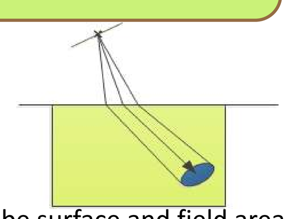
- Anisotropic materials behave differently depending on the orientation.
- Three different mode (= wave types) :
  - QL (quasi-longitudinal),
  - QT1 and QT2 (quasi-transversal).
- Two directions to be taken into account that are generally different in anisotropic materials :
  - Phase direction (= direction of the wave front),
  - Energy direction (= direction of the ray).

➔ A single interaction of a wave on an interface between two anisotropic materials can generate up to 6 new waves.



Algorithmic Principle [1]

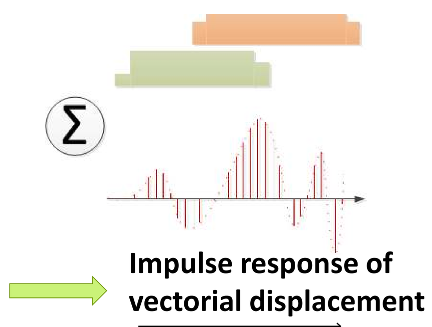
Pencils computation



- Probe surface and field area are **discretized.**
- Computation of paths following **Snell-Descartes** laws
- Computation of **pencil contribution** (**Amplitude** = divergence factor x Fresnel coefficients x dS), **Time of Flight, Duration**).

Delay laws application and impulse response

- **Temporal Shift** of pencil contributions according to delay laws.
- **Accumulation** of pencil contributions on Impulse response.

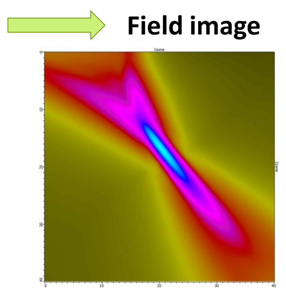


Impulse response of vectorial displacement ($\overrightarrow{IR\_displace(t)} \in \mathbb{C}^3$)

Extraction of field amplitude

- **Convolution** with probe signal
- Computation of displacement **module** signal
- Amplitude = maximum of the **envelope** of the displacement module signal.

Field image



A fast implementation for simple configurations

Pencil computation

Homogeneous isotropic specimen with planar surfaces

Path computation for immersion or contact probe

- For a single refraction at the interface between coupling material and specimen material **following Snell-Descartes** following equation can be written :

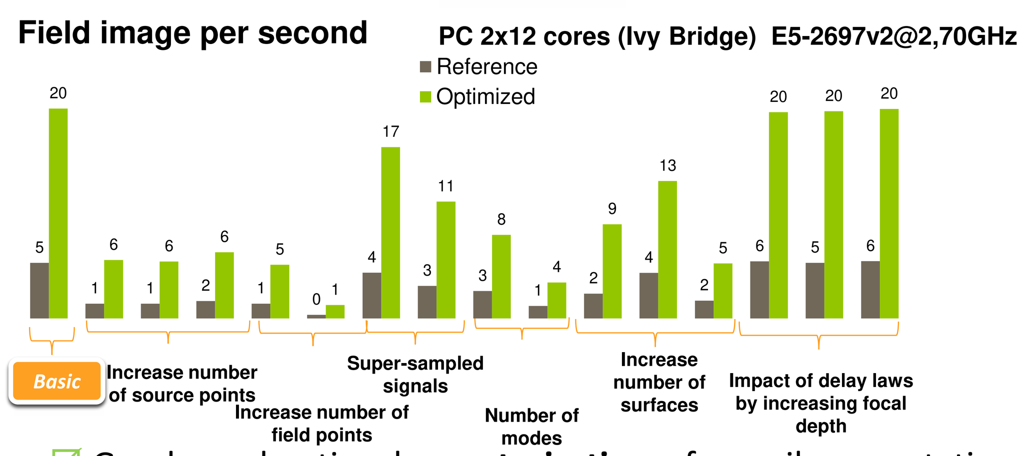
$$\frac{x_i - x_i'}{c1\sqrt{(x_i - x_i')^2 + z_i^2}} = \frac{x_i' - X}{c_2\sqrt{(x_i' - X)^2 + z^2}} \text{ where } X \text{ is unknown}$$

Non-linear equation solved via iterative **1D Newton method** (Similar to [2])

- Direct and indirect paths computation.
- Indirect paths = refraction + single reflexion without mode conversion.
- Validity of paths computed are tested : location of points on surfaces, occlusions.

Fresnel coefficient and divergence factor = analytic formulae.

Results



- ☑ Good acceleration by **vectorization** of pencil computation and amplitude extraction + use of Intel MKL FFT.
- ☑ **Good scaling** on recent CPUs.
- ☑ Up to **20 field image per seconds** on simple configurations

Interactivity goal on CPU is reached !

What's next ?

- Build and test of an AVX version (256bits – 8 floats/register)
- Use of Intel MIC architecture (**Xeon Phi**) – hope a good scaling
- Cuda reference version for **GPU** needs optimization (can benefit from SIMD implementation analysis on CPU).
- Functional extensions :
  - Longer ray paths (more reflexions/refraction with mode conversion) implies solving a set of N non linear equations (or use [3])
  - Non-planar surfaces (quadric, quartic) raise equations complexity.
  - Need for heuristics in order to avoid testing all the possible sets of surfaces ([2])

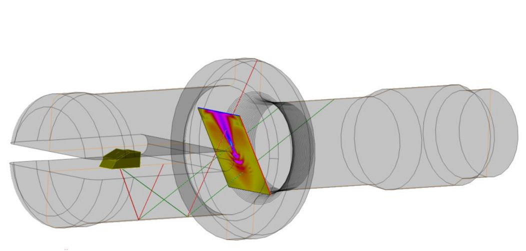
Difficult and still limited

Towards more complexity

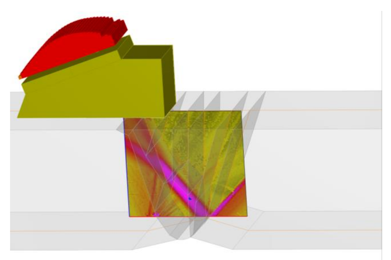
Complex cases

- **Any geometry** (non planar-surfaces, triangle meshes)
- **Heterogeneous** specimen
- Ray paths of **any length**
- Isotropic / **anisotropic materials**

Complex but still needs to be interactive (progressive computation)



3D CAD



Heterogeneous anisotropic weld

Pencil computation step is the most expensive step
Find paths between field point and probe surface + costly computation of divergence factor, Fresnel coefficients…

Basic tools

Preliminary results = fast ultrasonic ray tracer based on Intel Embree (CPU) and Nvidia Optix (GPU)

Acceleration of phase and energy directions computation for anisotropic material = Fast computation by intersection of meshed slowness surfaces and interpolation of normals. **Acceleration vs analytic = x7 to x8**

Number of ray paths with two reflections **Mrays / s**

Specimen	Material	PC 2x12 cores	Nvidia Gefore GTX Titan
Planar specimen (12 tri)	Isotropic	17,7	45,7
	Anisotropic	5,0	7,8
CAD Specimen (32 kTri)	Isotropic	6,9	6,9
	Anisotropic	2,7	3,0

Solutions considered

Progressive pencil step computation + intermediary US field images

Solution 1

Iterative geometrical method

For each field point and each mode, find pencils reaching the probe surface via a reverse beam tracer. Pencil solid angles are then gradually decreased, and occlusion or surface discontinuities are processed via an adaptive algorithm (like AD-Frustum [4]). At each iteration, for pencils reaching the surface probe, Fresnel coefficients are computed.

Solution 2

Perform a MC light tracing (or MCMC) with importance sampling, and possibly regularization (like in [5]) following ray paths starting from the probe until they reach the field area and contribute to the field points impulse responses. Pbm : *coherent sources* !

Perspectives and Conclusion

- **Interactive ultrasonic field** simulation for simple configurations can be performed on recent CPUs
- Tests on **AVX, AVX2 CPUs** and **Intel MIC** shall be performed for this method.
- A fast Cuda-based **GPU** implementation shall be carried-out.
- Non-planar surfaces or longer paths with wave conversion shall have to be taken into account.
- For **complex cases** (heterogeneous specimen with anisotropic materials, complex geometry and long ray paths) another method based on fast ray tracing shall be developed.
- Fast ultrasonic field simulations shall be derived to perform interactive computations of **echoes** on defects or specimen boundaries.
- These interactive tools shall be available in next **Civa software commercial releases.**
- As different codes developed for different hardware (CPUs and GPUs) will be available, an **auto-tuning** mechanism will be settled in order to choose automatically the best one for a given ultrasonic field configuration. Another mechanism might be developed to automatically tune computation options in order to keep a satisfactory level of interactivity ([6]).

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