FastScanning: achieving high scanning velocities in the phased array inspection of aeronautic components

J. Camacho \textsuperscript{1}, J. Cruza \textsuperscript{1}, E. Cuevas \textsuperscript{2}, S. Hernández \textsuperscript{2}

\textsuperscript{1} Ultrasonics Systems Group, ITEFI-CSIC, Madrid, Spain
\textsuperscript{2} TECNATOM S.A., San Sebastián de los Reyes, Spain

6th Symposium for NDT in Aerospace
MOTIVATION

**Objective:** Improve inspection speed on CFRP planar structures
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
2. Reception of M elements signals
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
2. Reception of M elements signals
3. Beamforming
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:
1. Emission with a subset of M elements
2. Reception of M elements signals
3. Beamforming
4. A-scan processing: filter, envelope detection, gates...

Processed A-scan

PROC PROCESSING

BEAMFORMING
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
2. Reception of M elements signals
3. Beamforming
4. A-scan processing: filter, envelope detection, gates...

\[ T_{\text{line}} = T_{\text{flight}} + T_{\text{beamform}} + T_{\text{process}} \]

Typically, this is the limiting factor, but sometimes could be the PRF.
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
2. Reception of M elements signals
3. Beamforming
4. A-scan processing: filter, envelope detection, gates...

\[ T_{\text{line}} = T_{\text{flight}} + T_{\text{beamform}} + T_{\text{process}} \]

THE PROCESS IS REPEATED FOR EVERY LINE
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
2. Reception of M elements signals
3. Beamforming
4. A-scan processing: filter, envelope detection, gates...

\[ T_{\text{line}} = T_{\text{flight}} + T_{\text{beamform}} + T_{\text{process}} \]

THE PROCESS IS REPEATED FOR EVERY LINE
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
2. Reception of M elements signals
3. Beamforming
4. A-scan processing: filter, envelope detection, gates...

\[ T_{\text{line}} = T_{\text{flight}} + T_{\text{beamform}} + T_{\text{process}} \]

THE PROCESS IS REPEATED FOR EVERY LINE

\[ T_{\text{image}} = L \times T_{\text{line}} \]
CONVENTIONAL LINEAR SCAN

FOR EACH LINE:

1. Emission with a subset of M elements
2. Reception of M elements signals
3. Beamforming
4. A-scan processing: filter, envelope detection, gates...

\[ T_{\text{line}} = T_{\text{flight}} + T_{\text{beamform}} + T_{\text{process}} \]

THE PROCESS IS REPEATED FOR EVERY LINE

\[ T_{\text{image}} = L \cdot T_{\text{line}} \]

STUDY CASE

- 4 arrays of 32 elements
- 6 elements aperture
- 2 element step
- Up to 50mm thickness
- 2mm scan resolution (y axis)

\[ v < 520 \text{ mm/s} \]

THE IDEA: do fewer shots

6th Symposium for NDT in Aerospace
FAST-SCANNING METHOD

FOR EACH B-SCAN:

1. Emission with **all** array elements
FAST-SCANNING METHOD

FOR EACH B-SCAN:

1. Emission with all array elements
2. Reception with all array elements

1 element linear scan → low resolution and SNR

if we generate all scans simultaneously

RECEPTION
FAST-SCANNING METHOD

FOR EACH B-SCAN:

1. Emission with all array elements
2. Reception with all array elements
3. Beamform all lines simultaneously
FAST-SCANNING METHOD

FOR EACH B-SCAN:

1. Emission with all array elements
2. Reception with all array elements
3. Beamform all lines simultaneously
**FAST-SCANNING METHOD**

**FOR EACH B-SCAN:**

1. Emission with all array elements
2. Reception with all array elements
3. Beamform all lines simultaneously
4. Simultaneous processing of all lines

\[
T_{\text{line}} = T_{\text{flight}} + T_{\text{beamform}} + T_{\text{process}}
\]

**IMAGE TIME IS EQUAL TO LINE TIME:**

\[
T_{\text{image}} = T_{\text{line}}
\]

**CONCLUSION:**

Fast-Scanning image can be up to L times faster than a linear scan of L lines.

**CASE OF STUDY**

\[
V < 540\text{mm/s} \rightarrow v \approx 30 \text{ m/s}!
\]

- Hardware capable of beamform 64 lines simultaneously is required!
- Reconfiguring our current system we could achieve 5 m/s

---

6th Symposium for NDT in Aerospace
Is Fast-Scanning image equivalent to conventional linear scan?

**IMAGE QUALITY**

**CONVENTIONAL LINEAR SCAN**

**FAST-SCANNING**

SLIGHT LOSS OF RESOLUTION

SLIGHT INCREASE IN AMPLITUDE
Is Fast-Scanning image equivalent to conventional linear scan?

**CONVENTIONAL LINEAR SCAN**

**FAST-SCANNING**

**LATERAL PATTERN IN THE FLAW**

Amplitude increase because we emit with all elements.
Is Fast-Scanning image equivalent to conventional linear scan?

**IMAGE QUALITY**

**CONVENTIONAL LINEAR SCAN**

**FAST-SCANNING**

**LATERAL PATTERN IN THE FLAW**

0.5 mm wider beam
Is Fast-Scanning image equivalent to conventional linear scan?
Is Fast-Scanning image equivalent to conventional linear scan?

**CONCLUSION:** FAST-SCANNING IMAGE IS QUITE SIMILAR TO THAT OF LINEAR SCAN IMAGE.
FOCAL LAW CORRECTION

COMMON ISSUE:

VERY DIRECTIVE BEAMS (3λ elements) → VERY SENSITIVE TO ARRAY/PART MISALIGNMENTS

0° tilt  2° tilt  4° tilt
FOCAL LAW CORRECTION

COMMON ISSUE:

VERY DIRECTIVE BEAMS → VERY SENSITIVE TO ARRAY/PART MISALIGNMENTS

0° tilt  2° tilt  -4° steering  4° tilt

Can it be done in real time?

6th Symposium for NDT in Aerospace
FOCAL LAW CORRECTION

Flight times to interface (echo-start) → Part tilt angle → Required steering angle

\[ \alpha = \sin^{-1} \left( -\text{sign}(t) \sqrt{1 - \frac{1 - t^2}{d^2}} \right) \]

\( t \): Flight time difference
\( d \): Array Pitch

6th Symposium for NDT in Aerospace
**FOCAL LAW CORRECTION**

Flight times to interface (echo-start) → Part tilt angle → Required steering angle → Focal law

- **2 shots**: A 0° shot is done before every image to obtain part tilt angle
  - ✓ More reliable
  - ✗ Slower
- **1 shot**: The angle for the next image is determined by current image
  - ✓ Faster
  - ✗ Less reliable

2 choices
FOCAL LAW CORRECTION

CONVENTIONAL

VIDEO

FAST-SCANNING

6th Symposium for NDT in Aerospace
CONCLUSION: STEERING ANGLE CAN BE CORRECTED IN REAL TIME WITHOUT SPEED SCAN DECREASE
HARDWARE REQUIREMENTS

- PARALLEL BEAMFORMING & PROCESSING
- REAL TIME (40 MSPS)
- LOW LATENCY

6th Symposium for NDT in Aerospace
Can be implemented in our system?

Yes. We have to develop:

- A new Firmware (digital design) for FPGAs
- Low level software (Drivers) in PC

**CASE OF STUDY:**

- 4 arrays of 32 elements
- 6 elements aperture
- 2 element step
- Up to 50mm thickness
- 2mm scan resolution

Scan Speed 5 m/s
(with a 32:128 system)
CONCLUSIONS

- It is possible to increment planar component inspection speed **over 1 m/s** without substantial resolution losses and correcting wave incident angle.

- A new technique called **FastScanning** has been presented. It’s based on the simultaneous transmission of all elements and beamform in parallel all lines of the image. For the case study, a inspection speed of 5 m/s can be reached.

- The proposed algorithm was **validated with a reference probe**.
Thank you
FastScanning: achieving high scanning velocities in the phased array inspection of aeronautic components

J. Camacho \textsuperscript{1}, J. Cruza \textsuperscript{1}, E. Cuevas \textsuperscript{2}, S. Hernández \textsuperscript{2}

\textsuperscript{1} Ultrasonics Systems Group, ITEFI-CSIC, Madrid, Spain
\textsuperscript{2} TECNATOM S.A., San Sebastián de los Reyes, Spain

6th Symposium for NDT in Aerospace
Is Fast-Scanning image equivalent to conventional linear scan?

**Lateral pattern in the natural focus**

- FastScanning → 25% wider (0.75mm in this case)
- NOTE: 0.75 << line step (2mm)

**Lateral lobe amplitude 5 times higher**

- NOTE: little relevance with scans at 0°