Use of Artificial Intelligence for Phased-Array data Analysis

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Abstract:
In the past 20 years, several steps have been taken to better the quality of non-destructive testing. The introduction of portable phased-array instruments led to recorded ultrasonic data which in turn led to a better control of the quality of the inspections. The introduction of online training led to a standardization of theoretical teaching which in turn led to better trained inspector and analysts. Still, problems remain in terms of defect detection, identification and sizing. Data analysis still fully relies on the skills of a human analyst even if the volume of data is exploding. Unfortunately, while there is an explosion in the volume of data to analyze, the number of qualified data analysts is not increasing accordingly. The result is shorter time to assess the data and longer working hours for the data analysts. New tools must be provided to data analysts, so they can perform their task more efficiently and accurately. In this paper, we review the challenges of analysing phased-array ultrasound data and the unique solutions provided by Artificial Intelligence

1. Introduction

Because of the fast-increasing volume of recorded ultrasound data produced and the time-consuming process of manually analysing this data, new tools must be provided to the analysts to increase their productivity. Automated data analysis software can help analysts by pre-processing the raw data. With such a tool, analysts can focus on the problems flagged by the software instead of analysing the whole volume of data. Artificial intelligence can be used to power the analysis process behind this type of software.

2. Data complexity

2.1. *3D vs. 2D*

Recorded phased-array ultrasound data represent a 3D volume. However, currently, this 3D volume of data is converted in 2D views (B-, C-, D-, S-Scans) for analysis. Since a simple weld scan usually involves a scan on each side of the weld, two 3D volumes are recorded. For each volume, four views are usually needed (A-, B-, C-, S-Scans) resulting in 8 different views to look at. To properly assess the data and correctly measure the possible defects, the data analysts must reconstruct the 3D volume in his head by switching between all these views.

2.2. Ultrasound waves

When introduced in a part, ultrasound waves bounce around until they lose their energy. The interactions of these bouncing wave between them and with the geometry of the part and their mode conversion from shear to longitudinal can produce background noise and phantom reflectors. Furthermore, reflections from geometrical indications can be confused with reflections from adjacent defects resulting in missed defects.

2.3. Amount of data

The amount of data in a single scan can be overwhelming by itself, so dozens of scans to be reviewed each day can lead to mental fatigue and lost of focus. Compounding the problem is the fact that the vast majority of the data does not have defects, hence the attention of the analyst is being further eroded by the monotony of the data.

3. Why use Artificial Intelligence

3.1. Analysing Data in 3D

The data is recorded as a 3D volume, so, to be more efficient, the data analysis should be done directly on the 3D volume of data. By using artificial intelligence and more specifically fully convolutional networks, it becomes possible to analyse 3D volumes instead of analysing 2D planes and stitching these analyses together to give a 3D analysis. Using Artificial Intelligence to analyse 3D volumes can be demanding as far as computing power is concerned.

3.2. Pattern recognition

When a human analyst is looking at a data set, he will look for the patterns representing possible defects while ignoring patterns representing geometrical indications or phantom echoes. Since the human analyst is doing his pattern recognition on 2-D views, he is probably looking at only a fraction of the patterns available in the data set.

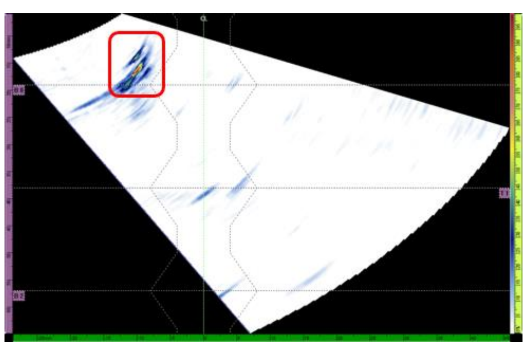

Fig. 1 Pattern of a defect

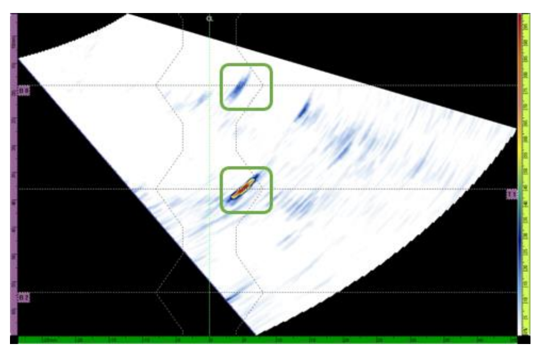

Fig. 2 Patterns of geometrical indications

Artificial intelligence or more specifically deep learning is very good at pattern recognition; hence, it can define 3D patterns that are indication specific. These patterns are probably ignored by human analysts because of their complexity and the fact that they are spanning several 2D planes. Artificial intelligence can thus enhance the abilities of the human analyst by pointing out possible defects that could have been missed by the analyst due to the ambiguity of the signal.

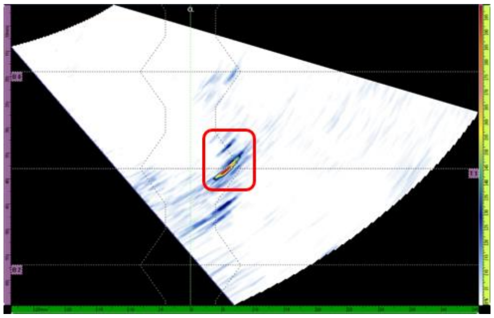

Fig. 3 Toe crack

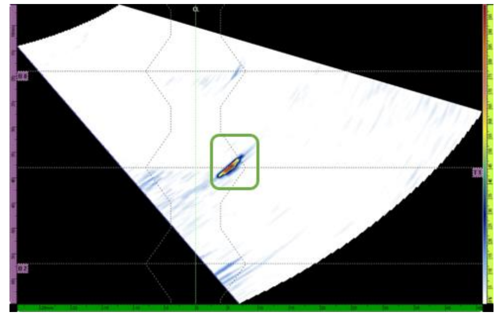

Fig. 4 Normal cap reflector

3.3. Data filtering

Artificial intelligence can be used to filter through huge amount of data to find the location of possible problems. The human analyst then only needs to analyse the parts of the data set containing possible defects.

3.4. Flexibility

Data produced by phased-array instruments are highly varied. Materials inspected (carbon steel, stainless, composites, plastics), weld types (V, double V, U, J), scan types (L-scan, S-Scan, FMC-TFM) are all variables that influence the characteristics of the data. Flexibility is thus needed to analyse phased-array ultrasound data. Deep learning provides the necessary flexibility through its learning capability. Deep learning algorithms can be trained on different data sets resulting in application-specific versions of the deep learning algorithms. The only drawback is that a minimum number of data sets is needed for the training of the deep learning algorithms. The more data sets, the better the accuracy of the analysis.

4. Training

4.1. Supervised learning

During supervised learning, the artificial intelligence is trained by feeding it data sets that have been analysed by a human analyst. The artificial intelligence will then learn to associate a pattern with a specific type of indication.

4.2. Un-supervised learning

When a large data pool is available, the artificial intelligence can be trained by feeding it all the data sets available and letting the artificial intelligence come-up with what it thinks are possible indications. A human analyst must then identify the different patterns discovered by the artificial intelligence.

4.3. Data augmentation

Data augmentation can be used when few data sets are available. Data augmentation is done by modifying existing data sets as to provide variants. These variations of the original data sets are fed to the artificial intelligence along with the original data sets providing the artificial intelligence with a bigger data pool.

4.4. Data bias

The diversity of the data sets fed to the artificial intelligence for training matters.

Analyst bias. If all the analysed data sets come from one analyst, the artificial intelligence can be bias towards his way of analysing data which can lead to mischaracterisations or worse omissions.

Solution: Have a pool of experienced analysts cross analyse the data sets before feeding them to the artificial intelligence.

Artificial defects bias. If all the indications in the data sets are from artificially created defects, the artificial intelligence can be bias toward artificial defects and not be as efficient to find natural defects.

Solution: Have a mix of artificial, natural and simulated defects

Welding technique bias. If all the data set come from the inspection of a single type of weld and the welds have been done with one welding technique, the artificial intelligence will be very good at recognising the indications in that type of weld but not as efficient for other types of welds or weld processes.

Solution: Diversify the data pool so it contains data sets from different types of welds done with different welding techniques.

Acquisition instrument bias. If all the data set are acquired with only one type of instrument, the artificial intelligence can identify patterns that are unique to this one instrument and not relevant to the analysis thus skewing the analysis.

Solution: Use data sets coming from different types of instruments.

5. Data quality

As for manual data analysis, data analysis with artificial intelligence requires high quality data. Before analysing the data set, it should be run through a primary artificial intelligence algorithm used to assess the quality of the data. Checks should be made for:

- The signal to noise ratio
- The amount of missing data
- Proper coupling between the probe and part
- The type of material
- The type of weld
- The thickness of the part
- The geometrical indications

6. Analysis

6.1. Computational power

Due to the size of phased-array ultrasound data sets (10 MB to 1 GB), analysing these data sets with artificial intelligence requires enough computational power to keep the computational time to a minimum. Although most desktop computers can run an artificial intelligence, especially the ones equipped with a Graphic Processor Unit, a better solution is to rely on dedicated servers. These types of servers can be configured to handle the heavy workload generated by the analysis of data sets. The best solution is to upload the data on cloud-based servers that can be scaled-up on demand to address the need for more computational power. This setup is especially efficient for projects with thousands of data sets to be analysed.

6.2. Human/artificial intelligence interaction

The human analyst must have access to the raw data and a proper analysis software to validate each indication provided by the artificial intelligence. To facilitate data visualisation, a 3D visualisation tool including a CAD drawing of the part should be used. The human analyst must have the possibility to override the artificial intelligence for the final decision.

6.3. Feedback loop

The feedback loop is an essential part of the artificial intelligence training. Analysis results provided by the artificial intelligence and corrected by a human analyst are fed back to the artificial intelligence for further training. It is recommended that the corrected data be reviewed by other analysts before feeding it to the artificial intelligence.

7. Conclusion

The use of artificial intelligence to assist data analysts will become more common as the burden put on the analysts' shoulders becomes more and more difficult to manage. It is not only a question of productivity, but also of security. The higher the workload of analysts, the more likely they are to make mistakes that could endanger lives.

As research brings better algorithms and a better understanding of the parameters influencing its functioning, the accuracy and repeatability of artificial intelligence analyses will continue to improve.