Tangential Homology for Defect Detection in the Time of Flight Diffraction Method (TOFD)

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Ultrasonic non-destructive testing (NDT) techniques are widely used in industry to evaluate properties of a component, material or system without causing any damage. The *time of flight diffraction method* (TOFD) is regarded as a valuable procedure for the detection of welding defects. We propose an innovative concept for NDT relying on tangential homology. The novel technique allows us to analyze topological properties of manifolds from discrete data. This in turn provides an automated classification of TOFD defects which does not require any interactions with a human operator.

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1 Introduction

The *time of flight diffraction method* (TOFD) is regarded as one of the most advanced methods in ultrasonic non-destructive testing (NDT), especially in steel industry, where welding quality is crucial to avoid productivity losses. TOFD provides sizing accuracy and a high probability of detection. Nevertheless, the interpretation of TOFD images and the classification of defects is still done manually, depending on the experience of a human operator. This paper proposes an innovative method for the automated classification of defects. To this end, a shape descriptor is computed using tangential homology, which involves the application of persistent homology to suitable tangential constructions [1]. Persistent homology is a powerful tool from algebraic topology, where the key idea is to build a filtration from point cloud data (PCD). During this process, the "birth" and "death" of different topological features, such as connected components and n-dimensional holes, can be tracked down.

2 Materials and Methods

The set-up of the TOFD method is shown in Figure 1. Ultrasonic waves are sent through the inspected material and the received information is recorded in an *a-scan*. Probes are moved and the combinations of all a-scans create a *b-scan*, which is a representation of the probes' positions versus time, where the echo amplitude is displayed in grayscale. *Volumetric defects* usually exhibit a parabolic shape in b-scans while *planar defects* produce linear shapes. But b-scans are often noisy. Therefore, a pre-processing step is applied [3] to obtain a denoised b-scan, see Figure 1.

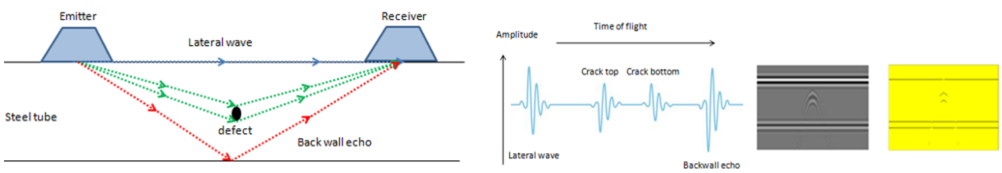

Fig. 1: From left to right: time of flight diffraction method (TOFD), a-scan, b-scan, and denoised b-scan.

The department of non-destructive testing of *Salzgitter Mannesmann Forschung GmbH* was commissioned by a supplier of welded large-diameter steel pipes for the oil and gas industry to establish a TOFD set-up in order to examine weld seams of longitudinal welded pipes inline. Measurements were performed on pipes with an outer diameter of 0.813 m and a wall thickness of 0.039 m. The ultrasonic beam angle was set by a wedge to $60°$ and a centre frequency of 5 MHz (transducer Olympus V310-SM) was used according to ISO EN DIN 10863. The probe center separation was set to 0.09 m which resulted in strong analogue signal strength which was recorded and digitized by an Olympus OmniScan MX test unit. With this set-up several hundreds of weld seams were tested. In doing so, it became apparent that it is possible to manually classify indications by similar appearances of flaws in the TOFD scan, see Figure 2. The proposed method for automated classification is based on our previous work [2], where persistent homology is linked to tangential and curvature information [1]. To further explain this, let us regard a given $2d$ PCD, resulting from a deconvolved b-scan, see Figure 3a. From the input PCD, we first compute a tangent complex $T(X)$, see Figure 3b. This is done as follows: Let $X \in \mathbb{R}^2$ be a curve and $T^0(X) \subseteq X \times \mathbb{S}^1$ be the set of all possible tangents in every point $x \in X$. Then, $T(X)$ is defined as the closure of T^0, i.e, $T(X) = \overline{T^0(X)} \subseteq \mathbb{R}^2 \times \mathbb{S}^1$. We

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compute the approximated tangent complex as the union of ε-balls in the fiber points, see Figure 3c. The next step is to create a filtration. In order to do so, the curvature at the original PCD is computed to obtain the approximated $T(X)$ filtered by curvature, see Figure 3d. Finally, we build a Vietoris Rips filtration to compute the β_0 barcodes of the shapes, see Figure 3e.

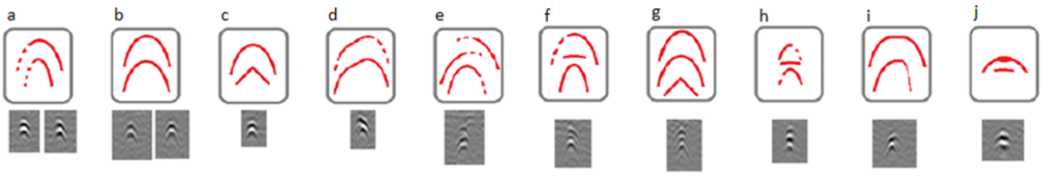

Fig. 2: Most common types of indications experienced in our TOFD real measurements.

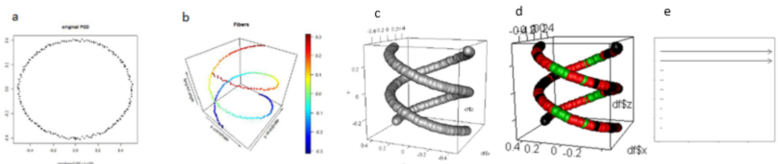

Fig. 3: (a) Curve PCD; (b) tangent complex $T(X)$; (c) approximated $T(X)$; (d) approximated $T(X)$ filtered by curvature; (e) β_0 barcode.

3 Numerical Results: Tangential Homology and TOFD Defects

The barcode shape descriptor is computed for the defects b, c and j in Figure 2, where the PCD is generated manually. The results are summarized in Figure 4. Given their topological properties, one cannot distinguish between the defects b and c. This is in contrast to our proposed method, where tangential information are used in addition. Figure 2c shows two parabolic shapes, where one has a kink. The singularity of the kink leads to a splitted tangent complex, due to the rapid variation of the curvature around that kink. The barcode from the defect in Figure 2b exhibits four half-infinite intervals, while that of defect c has eight (cf. Figure 4). The topology and smoothness for the defects in Figure 2c and j are coincident. The same half-infinite intervals, but a difference in curvatures, can be seen in the finite intervals. Barcode distances can be measured by using [1].

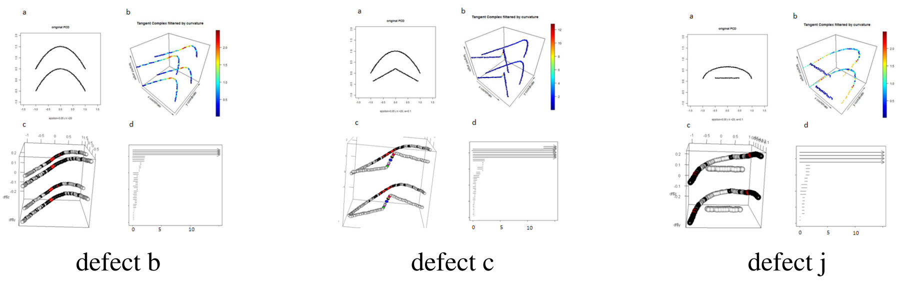

Fig. 4: Barcode shape descriptor for the defects b, c and j (see Figure 2) with their (a) defect PCD; (b) $T(X)$ filtered by curvature; (c) approximated $T(X)$ filtered by curvature; (d) β_0 barcode representation.

4 Conclusions

We have proposed an automated classification method for TOFD defects, where the classification problem is reduced to a comparison between barcodes. A shape descriptor is generated for denoised b-scans. By using a catalogue of barcodes computed from real data experiments we can determine the defect type. The method has been validated by comprehensive numerical examples. Persistent and tangential homology provide powerful methods for automated TOFD defect classification.

References

[1] A. Collins, A. Zomorodian, G. Carlsson, L.J. Guibas: A barcode shape descriptor for curve point cloud data. Computers and Graphics 28(6), 2004, 881–894.
[2] J.F. Cuenca and A. Iske: Persistent homology for defect detection in non-destructive evaluation of materials. The e-Journal of Nondestructive Testing, vol. 21, no. 01, January 2016, ISSN 1435-4934.
[3] F. Bossmann: *Model Based Defect Reconstruction in Ultrasonic Non-Destructive Testing.* PhD thesis, University of Göttingen, 2013.

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