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Defect characterisation from limited view pipeline radiography

Misty I. Haith*, Peter Huthwaite, Michael J.S. Lowe

Imperial College, Department of Mechanical Engineering, London, United Kingdom

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ABSTRACT

This work presents a method of characterising pipeline defects using a small number of radiographs taken at different angles around the pipe. The method relies on knowledge of the setup geometry and use of multiple images, and does not require calibration objects to be included in the setup. It is aimed at use in situations where access is difficult such as in subsea pipeline inspections. Given a set of radiographs, a background subtraction method is used to extract defects in the images. Using a ray tracing algorithm and knowledge of the experimental setup, the range of possible locations of the defect in 3D space is then calculated. Constraints are applied on potential defect shapes and positions to further refine the defect range. The method is tested on simulated and experimental flat bottomed hole defects and simulated corrosion patch defects with lateral and axial sizes ranging from 12.5 to 33.8 mm and thickness between 3 mm and 16 mm. Results demonstrate a good, consistent ability to calculate lateral and axial defect dimensions to within ±3 mm of the true size. Defect thickness calculations are more difficult and as such errors are more significant. In most cases defect thickness is calculated to within 4 mm of the actual value, often closer. Errors in thickness are due to overestimation, meaning the calculation could be used to place a maximum limit on potential defect size rather than as an actual estimate of the thickness. This would still be useful, for example in deciding whether a defect requires further investigation.

1. Introduction

Subsea pipelines are increasingly being used to transport vast quantities of oil and gas over thousands of kilometres. Inspection of these pipelines for potential corrosion and other defects is crucial for safe operation. Accidents can have devastating environmental and economic impact, amplifying the need for accurate, reliable detection and characterisation of pipeline defects. For many pipelines internal inspection techniques can be used. Internal methods include ultrasonics, magnetic flux leakage and eddy current inspection [1]. However in some cases internal inspection is not possible, for example due to lack of access, and external inspection methods must be used. External inspection of subsea pipelines presents unique challenges. Access is difficult, particularly in deep water areas which require remotely operated inspections and pressure resistant equipment. In addition, subsea pipelines often have thick insulation or concrete coatings, which means methods requiring surface or near surface contact, eg ultrasonics and eddy current testing, are not well suited as they would require insulation removal. Radiography holds a significant advantage over many other inspection methods in that it does not require surface preparation or insulation removal. Development of modern digital detectors has further improved the prospect of radiography, as digital images can be viewed almost in real time with no need to retrieve and scan computed radiography imaging plates or develop film. This makes radiography one of the most suitable methods for subsea pipeline inspection.

Techniques of pipeline corrosion mapping with radiography have been investigated and standardised [2,3] for use above water. Accepted inspection methods are the tangential and double wall techniques. The method used in practical subsea radiography is known as the Double Wall Single Image (DWSI) method. In this method, illustrated in Fig. 1 (a), the source and detector are placed close to each side of the pipe. As the upper wall is very close to the source any features are magnified across the whole detector, meaning that this method effectively just images the lower pipe wall, close to the detector. Corrosion is visible from the intensity change it causes, as more radiation reaches the detector in areas where the wall is thinner. The DWSI method is used in current practical subsea radiography as the relatively short source-to-detector distance reduces the highly attenuating and scattering effects of surrounding water. A variant of double wall imaging is Double Wall Double Image (DWDI), Fig. 1 (b), in which the source is set back from the pipe. In this case the upper wall is not magnified to the same extent, and both upper and lower pipe walls can be clearly imaged in a single exposure.

* Corresponding author.
E-mail address: misty.haith09@imperial.ac.uk (M.I. Haith).

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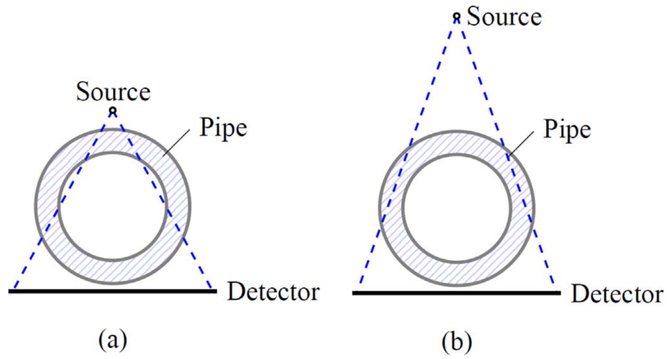

Fig. 1. Double Wall methods of radiographic imaging of pipelines for corrosion (EN 16407: part 2 [3]); for Double Wall Single Image, (a), the source is placed close to the upper pipe wall, while for Double Wall Double Image, (b), the source is set further back.

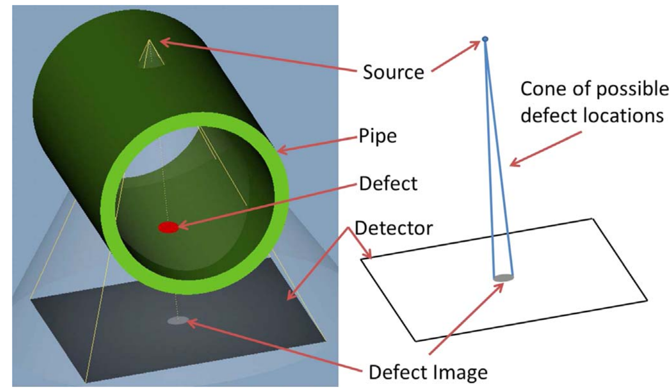

Fig. 2. Left: An example setup for radiography of a pipe containing a flat bottomed hole defect. Right: Using just the source and detector positions, along with the extracted defect pixels, a cone of possible defect locations is calculated through ray tracing.

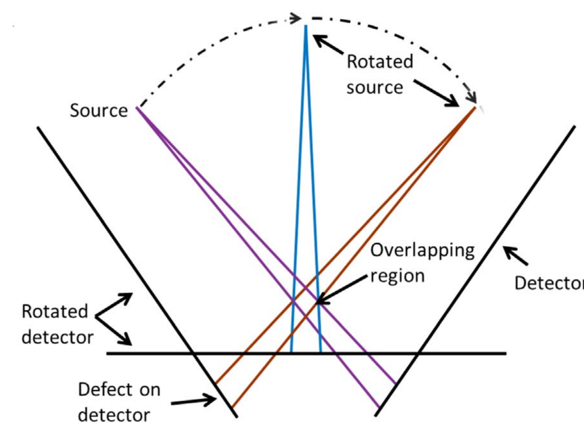

Fig. 3. Lines are drawn from each defect pixel to its corresponding source position. If this is repeated for multiple rotated images showing the same defect then the area within which the lines overlap is the area where the defect is. An example for three images shown here.

Double wall imaging is good for defect detection, imaging a relatively large portion of pipe wall in one exposure. For full coverage of the pipe wall the setup needs to be rotated about the pipe and images taken at different angles, but the number of images required is relatively low. However defect characterisation from double wall imaging can be difficult. Traditional methods of radiographic defect sizing rely on using additional objects of known size placed in the setup. For example, to estimate defect depth a step wedge must be included in the exposure, placed on the pipe as close as possible to the region of interest [3]. The step wedge is used in the resulting image to calibrate the relation of intensity to material thickness, allowing for defect depth to be calculated from its change in grey level. In a subsea environment, where the inspection is being controlled with a remotely operated vehicle, inclusion of objects such as a step wedge would add an additional layer of complexity to an already difficult inspection. Factors such as the positioning of the step wedge can impact the accuracy of the resulting defect characterisation, which could affect the reliability of the method. Therefore it would be advantageous to develop methods of defect characterisation for double wall pipeline radiography that do not require additional objects in the setup.

This work presents a method of pipeline defect characterisation based on knowledge of the setup geometry and the use of images taken at different angles around the pipe. The method does not require changes to the radiographic setup or additional objects. It has been tested on a range of simulated and experimental data and found to give good agreement of lateral and axial defect size, and reasonable estimates of defect thickness in most cases. The method has the potential to be fully automatic, requiring input of a set of images and setup geometry and from this calculating defect size without further manual intervention. The defect characterisation method is described in detail in the following section.

2. Defect characterisation method

For any radiographic setup, if the source and detector positions are known then the straight-line path from the source to each detector pixel in 3D space can be calculated. If the pixels in an image showing a defect can be identified then the range of possible positions and sizes for the defect is found. This is illustrated as the cone of possible defect locations in Fig. 2.

For a single image the range of possible defect locations and sizes is large, and no useful sizing conclusions can be drawn from this information. However, if multiple radiographic images are taken at different angles around the pipe, with the same defect visible in several, then the range of defect sizes and locations can be significantly narrowed. The process of tracing a path from defect pixels to their corresponding source is repeated for each image, with the possible defect now limited to the region where rays from all images overlap. An illustration in 2D is shown in Fig. 3 for the case of three rotated images of the same defect.

Characterisation from ray tracing of multiple images is significantly improved on single image results, particularly with regard to lateral and axial dimensions which are accurately determined at this point. However the depth resolution is still poor. In order to improve thickness calculations a series of constraints on possible defects are applied. For example, a constraint is applied on the pipe wall, and assumes the approximate location of the inner and outer pipe walls are know. Only that part of the possible defect volume which is inside the pipe wall can be defect, so any regions outside the pipe wall can be removed from consideration. Several other constraints are also applied and combine to greatly improve depth resolution.

The overall defect characterisation method is split into three parts: feature extraction, ray tracing and the application of constraints. The feature extraction method is based on background subtraction and is used to identify pixels showing a defect in radiographic images. This is followed by ray tracing, which makes use of the known source and detector positions and the angle of rotation between images to calculate the potential defect volume. Finally, constraints are applied.

2.1. Feature extraction

The feature extraction method is based on background subtraction. The object being imaged is a pipe, so radiographs taken at different angles around the pipe should look broadly the same if no defects are present. Therefore images with no defect can be used to define the background. The background here refers to changes in grey level across an image not due to a defect. These background intensity variations can