

Measurement Method for Welding Misalignment of Steel Pipes Using AR Markers and a Smartphone

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Abstract: A new method for measuring the weld displacement of steel pipes using AR markers and a smartphone camera was developed. Increasingly strict inspection specifications are now applied to welded steel pipes, but since the efficiency of manual inspection is still low, new automatic inspection methods are required. Therefore, we proposed a new method to measure weld misalignment from images of the end faces of steel pipes, and developed a smartphone application to realize automatic misalignment measurement of welded pipes simultaneously with saving the photographs as inspection records. As a result of experiments, the inspection time was shortened from 90 seconds to 25 seconds, and the measurement error when measuring actual pipes with wall thicknesses over 9.5 mm was less than 0.5 mm.

Keywords: Welded steel pipe, AR marker, Smartphone, Image processing, Automatic length measurement

1. INTRODUCTION

Steel pipes are important products used in the core parts of industry, and can be classified as seamless pipes, forge welded pipes, and welded pipes by their manufacturing process. One manufacturing process for welded pipes is the longitudinal-seam submerged arc welding (LSAW) method, where welded pipes are manufactured as shown in Fig. 1 by pressing a steel plate into a cylindrical shape and then welding its edges in a straight line. Large and heavy-gauge welded pipes can be produced by the LSAW method, and are widely used in products such as gas and oil pipelines, boilers, and building structures. Since leakage from these pipes is a direct cause of critical trouble or accidents in any application, regular assessment of the weld is required before the welded pipes are shipped in order to ensure that the welds have sufficient mechanical strength.

As the stringent requirements have been established for integrity assessment of welds on steel pipes in order to prevent premature failure of steel pipes for sour gas transportation, weld inspections of steel pipes are now becoming increasingly demanding. Although weld inspections were formerly carried out by sampling inspections, customers have gradually requested full weld inspection of all products. However, some of the weld inspection procedure is not fully automated, and efficiency is not currently sufficient because weld inspections include complicated manual measurement procedures which prevent automation. When a full inspection that includes the low-efficiency procedures mentioned above is necessary, welded pipe productivity may decrease significantly. Therefore, automation of weld inspections is necessary in order to increase inspection efficiency.

This research focuses on the development of an

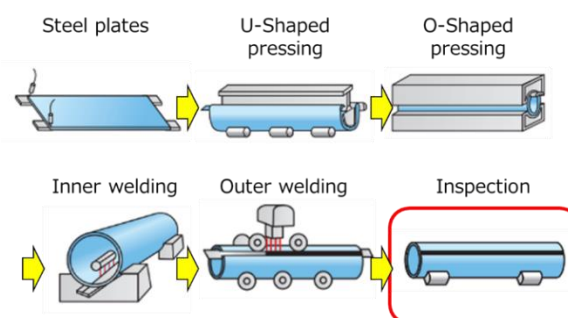


Fig. 1 Pipe manufacturing process by LSAW method

automated weld inspection method for steel pipes. The goals of the research are to improve the efficiency of complex weld inspections and to establish a full inspection procedure for welded pipes.

2. PREVIOUS RESEARCH AND GOALS

In this section, the concrete goals of this research are discussed by reviewing the current weld inspection procedure and previous research.

2.1 Pipe inspections

The weld inspection procedure for welded pipes includes various items, all of which evaluate the adequacy of weld strength. Most of these inspections are conducted by manual measurement. For instance, in the misalignment inspection shown in Fig. 2, inspectors examine the circumferential displacement between the inner weld and the outer weld. This inspection is carried out as follows: The fusion lines, which are defined as the boundaries between the base material and the weld, are identified on the end face of the welded pipe or the weld cross section, and misalignment is calculated based on the fusion lines, which are measured manually with a ruler or other measuring instrument. Since the

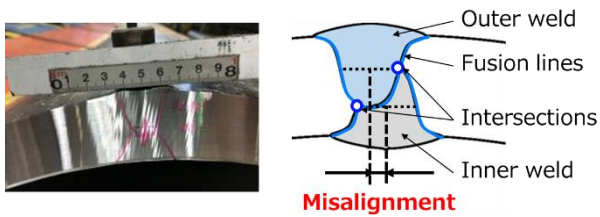


Fig. 2 Misalignment inspection on pipe end face.

measurement procedure used in misalignment inspections is complex, this inspection may become a bottleneck in the welded pipe manufacturing process. Therefore, this study focuses on an automation method for misalignment inspection of the welded cross section of welded steel pipes.

2.2 Previous research and goals

In this research, an image processing technique is applied to automatically measure misalignment in order to shorten the inspection time. Since the current misalignment inspection includes photographing the weld cross sections as an inspection record with a company smartphone, the cost of introducing new instruments can be reduced by utilizing those photos in automation. Another advantage of using smartphones is portability, which enables simultaneous inspections at any place when an urgent full inspection is required.

Previous studies on weld inspection using imaging techniques have examined a three-dimensional shape reconstruction method with multiple cameras [4], a light section method with line lasers [5], and measurement with a laser scanner [6]. However, those studies measured the three-dimensional geometry of welds on the cylindrical surface of welded pipes, which is not applicable to measurement of the weld cross section on a flat or conical pipe end face in misalignment inspection. In other studies, welds were inspected by using X-ray radiographic images in the radial direction [7][8], but few studies have focused on measurement in the pipe axial direction, which should be studied in order to develop a new measurement method.

Based on the above discussion, we developed a smartphone measurement application as a new automatic misalignment measurement technique which captures an image of the weld in the axial direction and measures the misalignment from that image.

3. PRINCIPLES OF AUTOMATIC INSPECTION METHOD

This section explains the principle of measurement of misalignment and the improved inspection procedure.

3.1 Image correction utilizing AR markers

As mentioned in the previous section, when inspectors take photos of weld with a company smartphone, the position and posture of the smartphone do not always directly face the weld, which causes distortion of the captured image. This distortion varies according to the relative positional and postural relationships between the smartphone and the weld cross section, and the length on

the captured image does not coincide with the real length.

Therefore, in the proposed method, AR markers are used to remove the distortion of the captured image. In the augmented reality field, AR markers are used for positioning, and information on the position and posture of the AR markers can be obtained from their apparent shape in a captured image [9]. It is known that the distortion in a captured image caused by the position and posture of the camera can generally be removed by applying a homographic operation to the image. This is an image morphing method commonly used in the image processing field [10]. Therefore, based on the two assumptions that the weld cross section is regarded as a plane, and the AR markers are placed in the same plane as the weld cross section, the captured image can be converted into an image by homography, as if captured with a camera placed directly in front of the weld cross section, with the predefined resolution, where the length on the converted image is proportional to its actual length.

Based on this method, a marker plate is created so that AR markers are placed around the weld cross section. When this plate is attached to the pipe end face so that its center is coincident with the inspection point, four AR markers with a known size and arrangement are located around the weld cross section. Magnet sheets are attached to the back side of the plate, and the plate surface can be easily arranged along the end face of the steel pipe.

The resolution and accuracy of image correction are directly related to the reliability of the measurement results. Resolution was set at 0.2 mm/pix so as to be larger than about 0.05 mm/pix, which is the substantial resolution of photography, and sufficiently smaller than 3 mm, which is the minimum tolerance of welding misalignment. The target value of measurement accuracy was set to 0.5 mm, which is the minimum length that inspectors can read from the scale of a ruler.

3.2 Extraction of fusion lines

The weld fusion lines are identified from the converted image. Since the contrast between the base material and the weld is insufficient, the fusion lines are traced by the inspector by hand, as in the current inspection process, and are then extracted by image processing. A blue pen is used to trace the fusion lines to distinguish the hand-drawn line from the red rust on the pipe surface, and the fusion lines are extracted as the set of pixels whose blue channel brightness exceeds that of the red channel by a predefined threshold.

3.3 Calculation of misalignment

The current manual procedure is imitated by an image processing procedure based on the input image of the fusion lines extracted as described in 3.2 above. First, based on the detected shape of the pen trace, the entire image is rotated to correct its inclination so that the horizontal direction of the image coincides with the tangential direction of the welded steel pipe. Next, the rightmost fusion lines and the leftmost fusion lines are searched from the both sides of the image. Then, the intersections on these two fusion lines are located respectively, by searching the point from which more

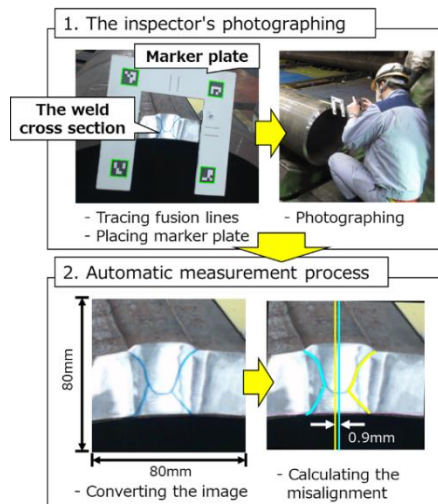


Fig. 3 Procedure of proposed method.

than two fusion lines diverge and go in outward direction. Finally, the centers of the inner and outer welds are defined as the midpoints of horizontal line segments, each of which is connected to the intersect detected as mentioned above to the fusion line on its opposite side. Misalignment is defined as the positional difference between these two midpoints in the horizontal direction.

3.4 Proposal of new inspection procedure

A new inspection procedure for misalignment measurement is proposed, as shown in Fig. 3, based on the principle described above. The inspection procedure is divided into two parts, 1. Preparation and photography by the inspector, and 2. Automatic measurement process. First, the inspector traces the fusion lines with a blue pen, and then photographs the weld cross section, with the marker plate located on it, using a smartphone. After the weld image is captured, the automatic measurement process is performed. This process is composed of homographic image conversion, extraction of the fusion lines, and calculation of misalignment, as described above. Although this procedure still includes the manual processes of tracing the fusion lines, attachment of the marker plate, and photography, significantly improved inspection efficiency is expected by reducing the manual work in the measurement process, as this has the heaviest workload in the inspection procedure.

4. EXPERIMENTS AND RESULTS

Experiments were conducted in both the laboratory and the factory to confirm the feasibility of the method proposed in the previous section.

4.1 Laboratory experiment using weld specimens

First, in order to confirm the function and accuracy of automatic length measurement of weld misalignment, an experiment was conducted using specimens of weld cross sections taken from actual welded steel pipes. The fusion lines on thirteen specimens were traced with a blue pen, the marker plate was placed on the weld cross section, and 10 images were captured from multiple photographic

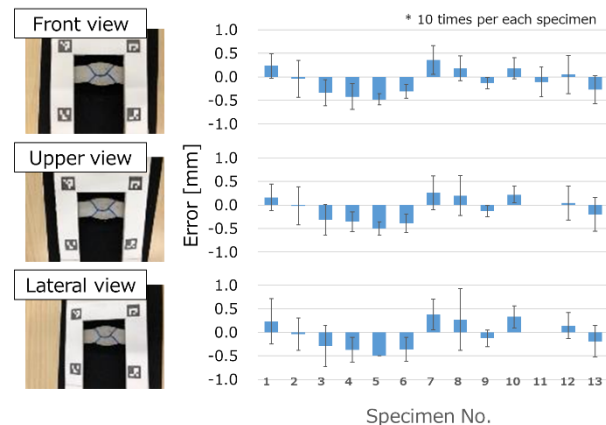


Fig. 4 Results of laboratory specimen experiment.

directions. The measurements of the weld misalignment obtained by the automatic length measurement system were then compared with the conventional manual measurement results, and the error between the two methods was evaluated.

From the evaluation results shown in Fig. 4, the average error was within ± 0.5 mm for all samples, confirming the possibility of automating weld misalignment measurement. However, deviations as large as ± 1.0 mm were also observed. This error should be improved, for example by eliminating deviations by averaging multiple measurements, or by optimization of the thickness of the pen used to trace the fusion lines.

4.2 Prototype measurement application

In consideration of actual inspection conditions, a prototype smartphone application for automatic misalignment measurement was developed and its feasibility was examined. This application was implemented in swift and Objective-C to run on iOS 12.0, with OpenCV version 3.4.12 as the computer vision library. As shown in Fig. 5, when the application is started, image capture by the camera starts, and when all the AR markers on the marker plate have been completely photographed, the result of the automatic misalignment measurement process is overlaid on a preview, which advises the inspector that the preparatory photography procedure has been completed. When the photograph button is pressed, the image after measurement is displayed, and when the save button is pressed, an image showing the measurement result, the images for debugs, and the log files recording the setting conditions are saved. In this experiment, the average image processing time per image was less than 0.2 seconds, which is sufficiently short to present the preview to the inspector in real time. The time required for the entire process from attachment of the marker plate to saving the measurement results was approximately 25 seconds per measurement. This is a significant reduction from the manual measurement time of 90 seconds.

4.3 Factory experiment

Next, an automatic weld misalignment measurement

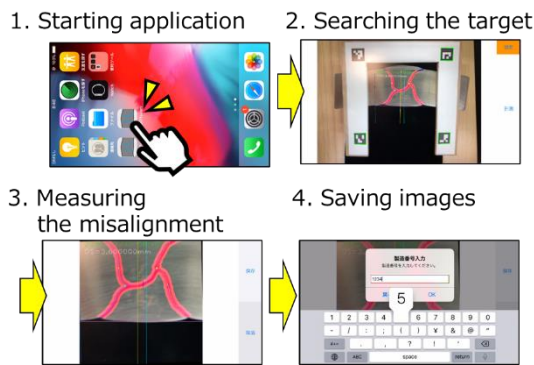


Fig. 5 Prototype application for smartphone.

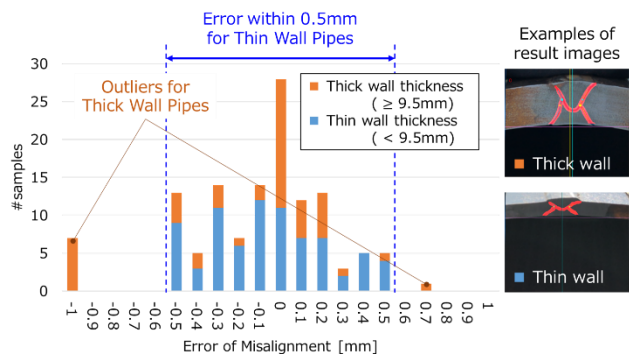


Fig. 6 Results of experiment with actual products.

experiment was conducted with the application described in 4.2 using actual products in the factory. In this test, the fusion lines were traced on actual welded steel pipes, the marker plate was set, and automatic misalignment measurement processing was performed by the application described above. Although the strength, color, and reflection of ambient light can affect image processing performance in an actual inspection environment such as a factory or a yard, the results of this factory experiment confirmed that detection and measurement of the fusion lines were not affected by actual environmental disturbances.

The measurement results obtained by automatic misalignment processing were compared with the values obtained by manual measurement, and the error between the two was evaluated. As shown in the Fig. 6, a test of 127 welded steel pipes revealed that the wall thickness had an impact on the results of automatic measurement. In a test of 50 welded pipes with wall thicknesses of 9.5 mm or more, error within ± 0.5 mm was achieved for all products, showing that misalignment measurement is possible by using the prototype application. However, error exceeding ± 0.5 mm was observed sporadically in 77 pipes with wall thicknesses under 9.5 mm. Additional verification indicated that this error occurred because the intersection points of the fusion lines deviated from the actual positions. That is, accuracy deteriorated because the fusion lines drawn on thin welded steel pipes tended to have intersections with small crossing angles, and positions outside the actual intersection were detected by the automatic misalignment measurement processing function developed in this work. Therefore, in the future, the image processing method will be reviewed to improve detection performance for pipes with thin thicknesses.

5. SUMMARY

An automatic displacement measurement system for welded steel pipe misalignment inspections using a smartphone and AR markers was constructed. This system calculates the weld misalignment in parallel with the conventional inspection record. As a significant reduction in inspection time was confirmed by laboratory and factory experiments, improved efficiency is expected in misalignment inspections of welded pipes.

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