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Technical Paper

A real-time weld line detection for derusting wall-climbing robot using dual cameras

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ABSTRACT

The real-time tracking of a weld line for the removal of rust can significantly improve the derusting efficiency and autonomy of a wall-climbing robot, wherein, weld line detection and identification is very crucial in order to realize weld line tracking. To solve this problem, the present study first established a seam tracking system based on dual cameras with auxiliary LED lights to present real-time image processing algorithms. A continuous recursive algorithm was then proposed to remove the burr of the edge of the weld line following image thinning. Furthermore, the identification rules of the weld line and the decision strategies of the final deviation were investigated. Finally, verification experiments were performed, wherein the experimental results indicate that the average processing time of a single weld image is less than 60 ms such that the success rate of weld line identification based on dual cameras reached 100%, thereby validating the reliability and effectiveness of the proposed detection methods for the cleaning process of the wall-climbing robot.

1. Introduction

The removal of rust in many large-scale structures, such as the pressure vessel and ship body section, is a very important process that must be executed prior to painting. However, there exist serious environmental pollution, low sand material recycling rates, high labor intensity, and health hazards for manual sandblasting operations, it has been gradually replaced by customized mobile robots that are suitable for this specific type of unstructured working environment. Wall-climbing robots have high flexibility and mobility, which allows a wide range of mobile operation and as such has attracted more attention for various applications [1–4]. The use of a wall-climbing robot for automatic derusting operations presents significant advantages to enhance the derusting efficiency, save costs, reduce the labor intensity and health hazard, and reduce environmental pollution as compared to manual sand blasting operation.

The tracking of a weld line, which connects two different ship body sections, first requires the detection and identification of the weld line itself using an appropriate sensing method. Previous literature have applied distance measurement [5,6], monocular vision [7,8], and structured light [9–16] for the detection of weld lines. Although the distance measurement method has higher precision and accuracy, difficulties often arise in the attainment of two-dimensional (2D) weldment surface information. Vision sensors can directly obtain original image and are widely applied in size measurement [17–19], automatic welding [20–24], and robot navigation [25–27]. Zhang et al. [28] proposed a vision-based monitoring system, which consisted of a laser structure light and dot matrix pattern, to measure the weld pool characteristic parameter in gas tungsten arc welding (GTAW) such as the length, width, and the convexity of the pool. Zhang et al. [9] also presented a cross-structure light to capture three-dimensional (3D) information of the weld line, which presented an RMS error within 0.407 mm. Although laser structured light sensors are simple, highly precise, have strong anti-interference abilities, and easily obtain 3D position and deviation information, it is very sensitive to the position's change. Moreover, the specific line information for the weld seam can only be obtained if these are scanned by the laser stripe. Xu et al. [20] presented a low-priced passive vision sensor to obtain 2D information on the weld seam and weld pool of the welding robot GTAW process. Although monocular vision only collected two-dimensional weld line information, the monocular vision sensor captured not a line information of weld seam scanned by laser stripe but a region information of the weld line image, thereby suggesting the ability of monocular vision in obtaining whole weld line contour

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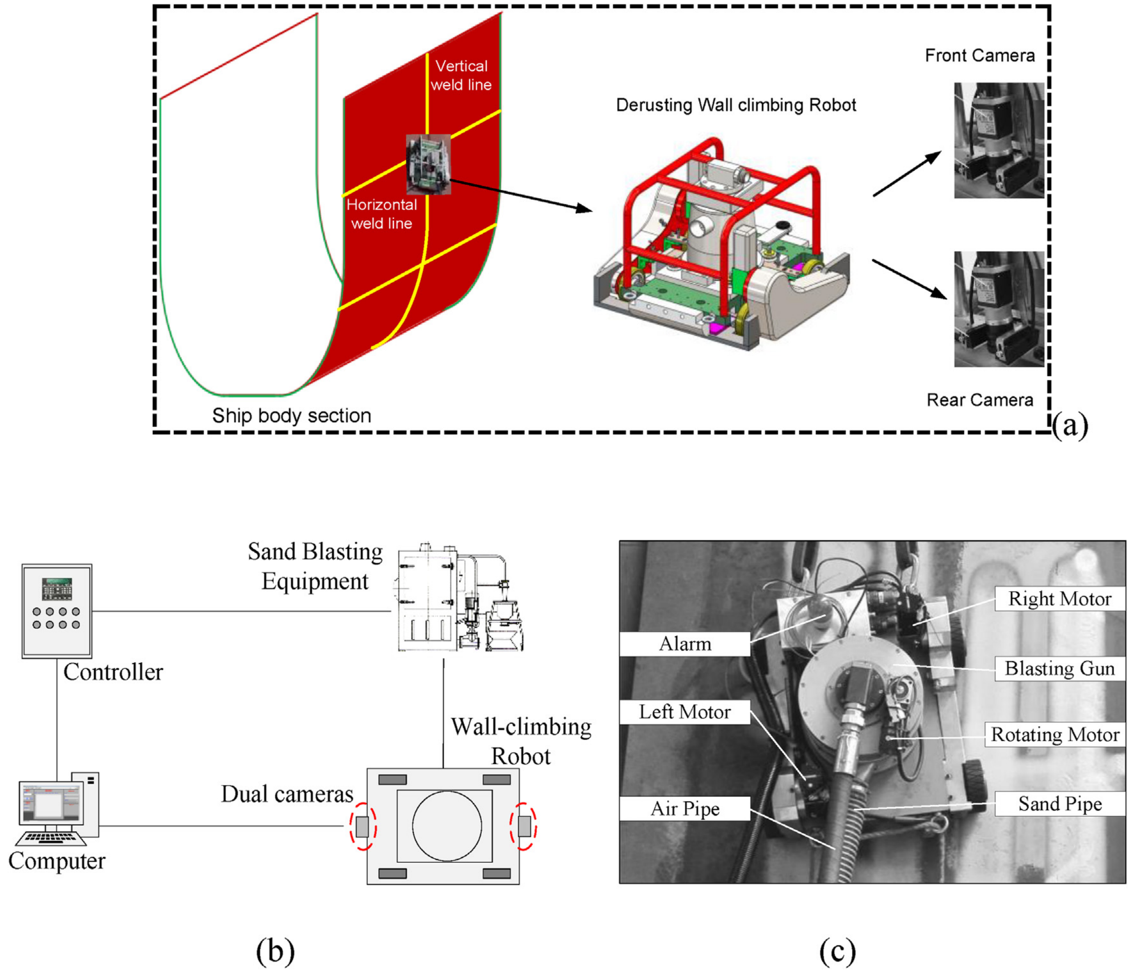

Fig. 1. Weld line detection and tracking system platform: (a) sandblasting wall-climbing robot platform, (b) control structure of the sandblasting wall-climbing robot, and (c) sandblasting wall-climbing robot.

information. Unlike the weld seam detection in welding process, weld line detection in the derusting process includes the detection of the T-intersection and the cross-intersection between the horizontal and vertical weld lines of a ship body section, which are then used to plan the motion path of the robot. In addition, the wall-climbing robot-based sandblasting operation is not significantly sensitive to variations in the height. Therefore, the present study characterized the monocular vision method as the more suitable method to tracking a weld line in the derusting of a wall-climbing robot.

Furthermore, it is essential to select a successful tracking method when derusting weld lines that connect different ship body sections because the external derusting conditions are very complex given the different degrees of corrosion, different working positions, and different levels of illumination and noise. It is necessary to employ dual camera with auxiliary lights in the tracking system to improve the reliability of the tracking system and avoid tracking failure during the derusting process.

The present study designed a dual camera tracking system with auxiliary lights, the internal and external parameters and hand-eye relationship were calculated, and presented the image processing and feature extraction methods. The rules for weld line identification and deviation decision strategies were then investigated. Lastly, experiments were performed to verify the effectiveness of the weld line detection methods.

2. Tracking system based on dual cameras

2.1. Derusting wall-climbing robot system

The weld line detection and tracking platform is presented in Fig. 1. Fig. 1(a) illustrates the sandblasting of the wall-climbing robot with a tracking function, which was mainly composed of a wall-climbing robot, front and back vision sensors, and sandblasting derusting equipment. Fig. 1(a) also presents a scene that depicts the wall-climbing robot moving along the vertical or horizontal weld line of the ship body section to remove rust from the weld line in the wild. Fig. 1(b) illustrates the control structure of the wall-climbing robot, wherein two cameras were assembled at the front and back of the wall-climbing robot, thereby transferring weld line images to the PC for the image processing of the derusting process. A sandblasting wall climbing robot is presented in Fig. 1(c), wherein magnetic adsorption was used as the main adsorption force, the left and right servo motors were used to drive, and the blasting equipment was assembled at the center of the robot.

2.2. Dual camera vision sensor system

Fig. 2 illustrates two cameras that are assembled to the front and back of the wall-climbing robot, respectively. Each image acquisition system was composed of a camera, a camera bracket, and white auxiliary LED lights. The camera was assembled to the camera bracket and was adjustable in the four directions of the camera