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A novel laser vision sensor for weld line detection on wall-climbing robot

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ABSTRACT

In this paper, we present a cross-structure light (CSL) sensor, that consists a structured light projector and a camera, for weld line detection. The structured light projector projects cross laser beams on the weldment to form cross stripes, which are captured in images by a CCD camera for measurement. We use feature points, a planar target and a homograph matrix to calibrate the sensor. We also propose an effective approach to extract laser stripes in images for weld line detection. Experiments show that the CSL sensor can capture 3D information of the weldment with very low measurement error, and the weld line detection approach is effective in wall-climbing robotic platform navigation.

1. Introduction

To perform non-destructive testing very important to guarantee the safety operation of lots of industry facilities, such as towers of the wind turbines and oil storage tanks. In automatic non destructive testing (NDT) systems, automatic weldline detection and tracking can navigate moving platforms and improve the testing performance and efficiency significantly.

In literature, distance measurement [1,2], monocular vision [3,4] and structured light some approaches have been applied to detect the weld lines [5,6]. Distance measurement method usually uses the distance sensor arrays to obtain depth estimates of points reflecting the convexity shape of excess weld metal on the weld line. However, the depth points are discrete although distance sensor arrays have complex mechanical structures. In addition, depth information is invisible, which makes it difficult to operate the system when manual intervention is required. Monocular vision approaches are simpler and more intuitive than those based on distance sensor arrays, however, it is often difficult to obtain the 3D information of weldment surface by a single camera. Moreover, weld lines on painted surface often have similar color with their background, which makes it difficult to distinguish the weld lines from their background.

Laser structured light sensors have attracted more and more attentions and are widely used in robot areas, such as automatic welding [7,8], industry inspection [9–11], 3D measurement [12,13], quality control [14], and robot navigation [15–17], for its simplicity, noncontact and strong anti-interference abilities. It is observed that most of the weld lines have weld convexity formed in the welding process. Structured light that can capture these convex shapes with a visible manner is introduced to detect and track weld line.

In terms of the laser projected patterns, the system normally projects a laser spot, a single laser stripe, or multiple laser stripes. More patterns like a circle, concentric multiple circles and a grid are also used. In industrial environment, for instance, the single laser stripe is widely used for weld seam detection in welding process. Unlike weld seam detection, weld line detection includes detecting T-intersection between horizontal and vertical weld lines of tanks and towers; therefore, single laser stripe is unsuitable for the weld line detection. In order to solve this problem, a cross laser stripe-based structured light sensor is presented in this paper.

In our weld line detection and tracking system, a CSL sensor is designed to project a red cross laser beam on the weldment surface to form a cross laser stripe which is then captured by a CCD camera. The laser stripe projected by CSL can reflect the height of weld convexity, detect horizontal and vertical weld lines simultaneously and be insensitive to illumination changes. The CCD camera captures 20 color video frames per second in H.264 format with resolution of 640×480. Captured video sequences are transmitted to PC with a wireless module for weld line detection and tracking. The operations of detection and tracking are performed on PC. Detected and tracking results will be transmitted

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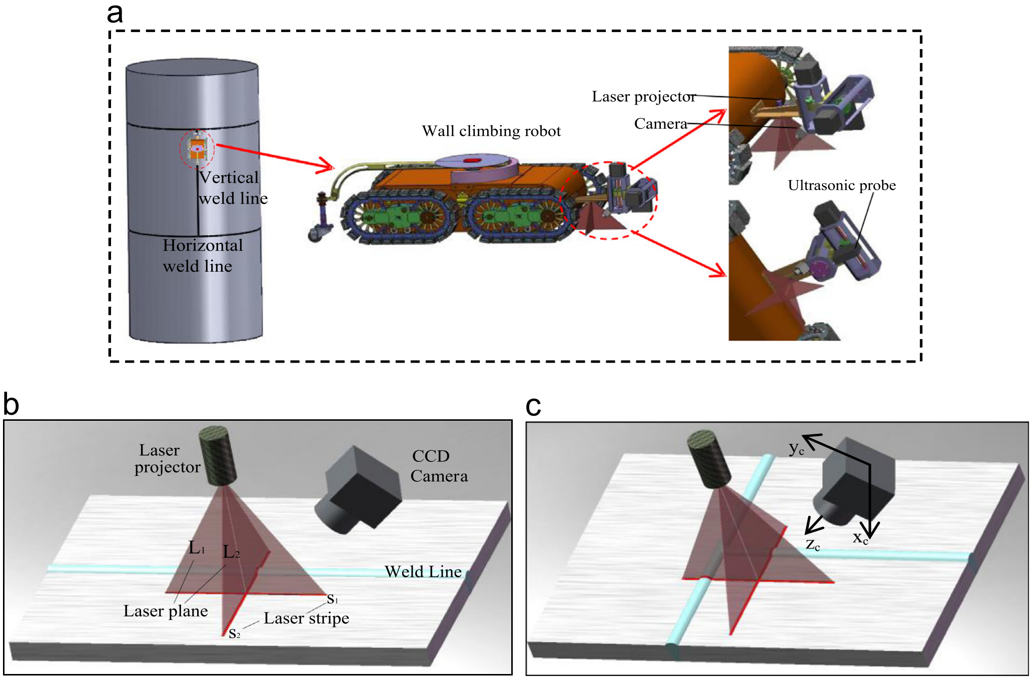

Fig. 1. Weld line detection and tracking system. (a) The platform. (b)The CSL projector and imaging CCD on straight weld line, and (c) on cross weld lines.

Table 1
Configuration of the CSL sensor.

Device	Parameters
Camera	CCD: SONY: 1/4 in. Resolution: 640 × 480 pixel Pixel size: 5.6 μm × 5.6 μm Frame rate: 20 fps Focal length:8 mm Field of view: 43.7°
Laser projector	Size:ϕ 9 × 23 mm Wavelength: 635 nm Operating voltage: DC 5 V Operating current: 20–50 Ma Output power: 5 mW Fan angle: 60°

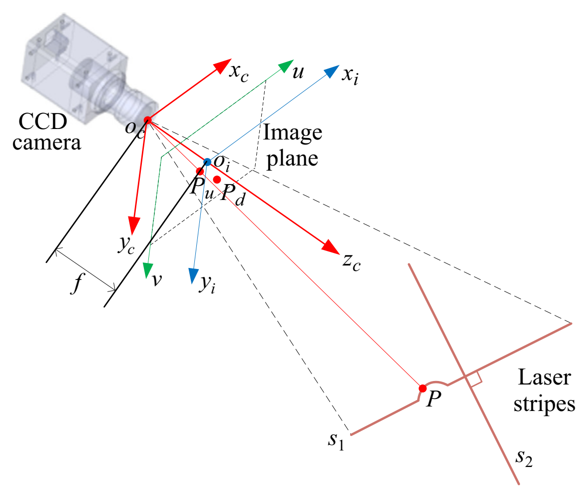

Fig. 2. Measurement model of the CSL sensor.

back to robot to feed into a PID controller and then converted into the Cartesian space of robot end-effecter frame to control its movement. The controller is described in [18] and the weld line localization is described in [6]. The details of both are omitted in this paper.

The remainder of this paper is organized as follows. In Section 2, the model of the CSL sensor is introduced. In Section 3, the approaches of extracting the laser stripe and localizing sub-pixel location are presented. In Section 4, the calibration approach for the CSL sensor is described. We present calibration experiments and actual measurement experiments of the sensor in Section 5 and conclude the paper in Section 6.

2. Model of CSL sensor

Our weld line detection and tracking system platform is shown in Fig. 1(a). It is composed of a wall-climbing robot, an ultrasonic device of NDT and a CSL sensor. The configuration of the CSL sensor is shown in Table1. Fig. 1(b) and (c) illustrate the CSL projector and image capturing CCD on straight weld line and cross weld lines, respectively. The laser projector is fixed on the robot and perpendicular to the weldment. Two stripes s_1 and s_2 are formed by intersection lines between weldment and two orthogonal laser planes L_1 and L_2.

The laser projector projects a cross laser beam on the weld line, forming convex light stripe around weld line. According to the laser triangulation measurement method, the 3D information of the weldment surface can be obtained by calculating the camera coordinates of the points on the light stripes transformed from the image coordinates. In general, when the robot moves along the straight weld line, only a convex arc exists on the stripe s_2, as shown in Fig. 1(b). When the robot is close to a T-intersection of vertical and horizontal weld lines, two convex arcs will appear at the strips, as showed in Fig. 1(c). The sensor can simultaneously detect the locations of the horizontal and the vertical weld lines, which are used to plan the motion path of the robot.

According to the above principle, the measurement model of CSL sensor is described in Fig. 2. $o_c - x_c y_c z_c$ is used to describe the camera coordinate system. $o_c o_i = f$ denotes the focal length of the camera. $o_i x_i y_i$ denotes the image coordinate system. In camera