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Principle of an innovative visual sensor based on combined laser structured lights and its experimental verification

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HIGHLIGHT

- An innovative multi-functional monocular visual sensor is proposed and devised.
- The detection algorithms are derived from the principle of optical triangulation.
- A test platform was established and the detecting experiments are carried out.

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ABSTRACT

To promote development of sensing technology applied in the welding process and improvement of production automation in the welding manufacturing industry, an innovative multi-functional monocular visual sensor based on combined laser structured lights (single-line & cross-lines) is proposed and devised. It can realize the detection of cross-sectional size parameters of welding groove, space position and posture of welding torch relative to the weldment or welding groove by using monocular vision. Its calibration makes full use of the intrinsic parameters, such as its internal structure parameters and the focal length of industrial CCD camera. Therefore, it is unnecessary to re-calibrate when the position and posture of welding torch have some variations during the welding process or the visual sensor reassembles with the welding torch, which availably improves the adaptability of this sensor in engineering application, so that it can apply to the welding process with complex space welding trajectory. Furthermore, with the use of combined laser structured lights, it effectively eliminates the problem of information loss in depth commonly existing in usual monocular visual sensor. Meanwhile, all the detection functions of this sensor are derived from the processing results of a single image captured by industrial CCD camera, which avoids the problems of time-consuming and large amount of calculation resulting from multi-images processing (multi-vision method or multi-angle time-sharing imaging in monocular vision), and thus significantly improves its real-time performance in engineering application. Its functional detection algorithms for the cross-sectional size parameters of welding groove and the height of welding torch derived from the principle of optical triangulation are given. After establishing a test platform, we carried out a series of detecting experiments for different types or sizes of V-type butt groove. By image processing, recognition and extraction of the feature points, the cross-sectional size parameters of welding groove and the height of welding torch calculate out through the derived detection algorithms. The acquired detection results have enough accuracy and their maximum relative errors are not exceeding 3.9%, which demonstrate the rationality of the physical design for the proposed visual sensor and the validity of the derived detection algorithms.

1. Introduction

Welding was, is and will forever be one of the essential materials processing methods in modern manufacturing industry. In the United States of America, Germany and other industrial developed countries, the automation rate of welding manufacturing has reached 80% or above, but its intelligent level still requires to be further improved. In China, the corresponding automation rate is only approximately 40% [1], therefore it is urgent both in development of automatization and improvement of intellectualization.

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In welding manufacturing process, there unavoidably exist not only machining tolerances and assembly errors on the workpieces to be welded and their welding grooves, but also thermal deformation during the arc welding process, which make the arc welding robots could not fully accommodate to the actual welding conditions, thus result in low production efficiency and poor weld formation quality. To increase the automation rate and improve the intelligent level of welding fabrication process, some appropriate sensors are frequently adopted to detect the on-site information in real time during the welding process, such as the cross-sectional size parameters of welding groove, the spatial position and posture of welding torch relative to being welded groove or joint, and others. The effective sensing approach should be able to acquire much valuable information and their variations, thus offer assistance for the welding robot or automatic equipment to realize their automation, flexibility and intelligence during the welding production process.

With the development of welding industry, the real-time sensing technologies applied in the arc welding process have also made a great progress. The arc sensors and the visual sensors are two types of most widely researched and applied sensors in the field of arc welding. However, the arc sensors have some limitations in their application range because of their potential difficulty in establishing a precise mathematical model between the arc length and the welding current (welding power supply with constant voltage output characteristic) or arc voltage (welding power supply with constant current output characteristic), thus only limited joint types are applicable [2]. For example, it is not much suitable for sensing the variation of arc length and the offsets of welding torch relative to being welded groove or joint in the welding process of sheet metal weldment, and the weldment with asymmetrical or small sizes welding grooves. Instead, the visual sensing technology has been made rapid development with the progress of computer, photoelectric and image processing technology since David Marr proposed a new theory of computer vision in 1977 [3]. Now, the visual sensor mainly includes two categories: passive and active vision methods, according to whether having external light source arranged artificially. The passive vision method directly uses ambient or arc light as the background light source; the concept of active vision method was first proposed by Bajcsy in 1982 [4], and the image information of the welding region of interest was obtained by using an auxiliary external light source. The laser structured light has most successful applications as auxiliary light source in the active vision method because of its advantages of excellent directivity, mono-chromaticity, coherence, concentrated energy and so on.

Compared with other sensing technologies, the visual sensing technology based on the laser structured light has the following unique advantages as applied in the welding process.

(1) With capability to acquire a large amount of information with high precision, including the cross-sectional size parameters of a variety of joint types or welding groove forms, and the spatial position and posture of welding torch relative to being welded workpiece, groove or joint. Thus the multiple functions such as the weld seam tracking, the automatic planning of weld bead in multi-pass welding, the process parameters adaptive controlling during welding process and the bead appearance inspection after welding could be realized based on the acquired high precise visual information.
(2) Due to non-contact with the workpiece being welded, it does not interfere with the implementation of welding process, and is not be affected by the high temperature of weld pool. Further, it can effectively prevent the interference from the electromagnetic field, arc light, spatter and dust during welding process. Hence, it has strong anti-interference ability and environmental adaptability.
(3) The processing on the captured image and extraction of feature parameters are relatively simple and stable, thus it has outstanding authenticity and real-time performance.

The visual sensing technology based on the laser structured light has gradually become the focus and mainstream of research and application in the field of welding. In this paper, a new multi-functional monocular visual sensor was proposed and designed, which based on the combination of one cross-lines laser structured light and another single-line laser structured light. The representative detection algorithms of the proposed visual sensor were deduced which based on the principle of optical triangulation. The experimental verification were performed by establishing a test platform and applying to different types or sizes of V-type butt groove, and the detection functions and algorithms in relation to the cross-sectional size parameters of V-type butt groove and the height of welding torch were verified. Compared with the traditional visual sensor based on the single-line laser structured light, this innovative visual sensor enables the integration of sensor improved, the detection functions of spatial parameters realized based on the processing of only one image from the monocular vision, and the calibration of visual sensor before and during use are optimized. Therefore, it can effectively improve the practicality and real-time performance of the visual sensor based on the laser structured light in welding manufacturing process.

2. Characteristics of visual sensor based on laser structured light in welding

There are mainly two types of laser visual sensors used in the welding manufacturing process, based on scanning or structured light. The scanning mode of laser visual sensor has a large field of view, but the detection accuracy is relatively low and the system structure is complex. Furthermore, its real-time performance is relatively poor because of the influence of scanning speed. More applications are visual sensors based on laser structured light, especially in the applications of high-precision detection and parameters control or high-speed weld seam tracking.

The characteristics of the visual sensor based on the laser structured light are mainly determined by the type of laser structured light used and the number of cameras. For the detection of cross-sectional size parameters of welding groove and the weld seam tracking, the most widely used type at present is the monocular visual sensor based on single-line laser structured light. The premise of this type sensor realizing the detection functions is that the height and space posture of the sensor relative to the being welded workpiece are predetermined and the sensor is pre-calibrated accordingly. This type of visual sensor requires recalibration when its height or space posture changes, or when the visual sensor reassembles with the welding torch. In other words, if this type of visual sensor mounts on the welding torch, after calibration, the height and space posture of the welding torch relative to the being welded workpiece must remain unchanged to ensure the effectiveness of the detection. Obviously, this limits its application in complex space welding trajectory because of unavoidably existing variation of the welding torch in its height and space posture. Consequentially, this kind of visual sensor cannot realize the function of detection on the height and space posture of welding torch relative to the weldment when the space posture of welding torch are changing constantly in practical fabrication.

For the visual sensor based on cross-lines laser structured light, it mainly used for the weld seam tracking and its advantage is that the track of welding groove is realized directly using the intersection point of the cross-lines of laser structured light [5,6]. However, when applied to the detection of the cross-sectional size parameters of welding groove, there exist the similar problems with the visual sensor based on single-line laser structured light. With the laser scanning method or the movement of detected objects, such a visual sensor has more application for the measurement of the object surface morphology [7,8] but with relatively complex system and poor real-time performance.

The visual sensor based on multi-lines laser structured light is also a common type with relatively large number of research and application