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RESEARCH ARTICLE

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Laser vision sensing based on adaptive welding for aluminum alloy

Abstract A laser vision sensing based on the adaptive tungsten inert gas (TIG) welding system for large-scale aluminum alloy components was established to fit various weld groove conditions. A new type of laser vision sensor was used to precisely measure the weld groove. The joint geometry data, such as the bevel angle, the gap, the area, and the mismatch, etc., aided in assembling large-scale aerospace components before welding. They were also applied for automatic seam tracking, such as automatic torch transverse alignment and torch height adjustment in welding. An adaptive welding process was realized by automatically adjusting the wire feeding speed and the welding current according to the groove conditions. The process results in a good weld formation and high welding quality, which meet the requirements of related standards.

Keywords inert gas welding, optical sensors, adaptive system, tracking, aluminum alloy

1 Introduction

In aerospace manufacturing, the requirements of quality and process control have increased rapidly along with the applications of new materials and technologies. This marks the trend that automatic welding technology has now become the main welding process in aerospace manufacturing [1]. However, passive inspections for welding quality have not been able to meet the demands of quality control and management. Therefore, actively monitoring and controlling the welding manufacturing process is still necessary [2].

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For large-scale aluminum alloy structure components, there are three factors that affect the precision of the parts to be weld: 1) Because of their big size, the parts need to be adjusted several times when assembling. Despite this, position errors still exist, which could cause different gaps or mismatches. 2) Keeping the whole joint consistent and repeatable is very difficult because of the limitation of the machining accuracy. 3) In the welding process, the position and dimension of the joint would be changed by distortion resulting from the arc heating and its relative stress.

Usually, traditional welding equipment is limited by the adjustment of the torch position and the welding parameter. Therefore, the welding conditions or the parameters should be set properly before welding. The equipment cannot be automatically adjusted for various groove conditions and joint position. On the current production line, the welding torch position (height and lateral) and the parameters are adjusted on the spot on the basis of the operator’s observation and experience. This is quite difficult for the operators. Nevertheless, traditional welding equipment hardly meets the current requirements of the manufacturing process monitoring and control for welding products.

It is well known that among the methods of welding process sensing, machine vision is the best sensing method with the most plentiful information. There are two types of machine vision: the passive mode and the active mode [3]. In the passive mode, the arc or the weld pool is the observation target. No measurement error results from factors such as heat distortion. Thus, it is able to acquire data of the joint or the weld pool and is propitious to the adaptive welding quality control [4]. Unfortunately, direct observation is liable to be disturbed by the arc that there has been no report of its good industrial application so far. Thus, active vision, especially the laser triangulation-based scanning method, has become the main vision sensing method applied in industries. The main feature of laser vision sensing is that it can obtain precise joint geometry and position [5], which can meet the requirements of real-time seam tracking [6] and adaptive process parameter control [7].

According to the status and the requirements of welding large-scale aluminum alloy components in the aerospace industry, the real-time acquisition of welding process data is carried out. Welding process parameters are optimized and adjusted online for the presented weld size and its consistency. Based on laser vision sensing, the following features are achieved: 1) precise measurement of groove geometry; 2) additional measurement for the pre-weld assembly and its quality control; 3) seam tracking, including automatic torch lateral alignment and height adjustment; and 4) online adaptive welding parameter adjustment, including welding current and wire feeding speed.

2 System design and experiment equipment

A special purpose welding system was designed for the adaptive aluminum alloy tungsten inert gas (TIG) welding with wire feeding. The system included the welding equipment, a laser vision sensing-based controller, I/O interface, a parameter data acquisition system, and related software.

1) Welding equipment

The welding equipment was composed of a welding power source, a torch, a wire feeder, a fixture, a welding carriage (longitudinal weld), or a rotating positioner (for the circumferential weld), and other related auxiliary devices, such as water cooling, gas supply, etc. Considering the present conditions, the power source (Kemppi PSS5000), the fixture and the positioner were kept for the new system. The devices that could critically affect the welding quality improvement, the adaptive welding process control and the online monitoring, include the new type of high-quality torch, wire feeder and the welding carriage or the positioner.

2) Laser vision sensing based on adaptive control system

The laser vision sensing on the basis of an adaptive control system measured the geometry of the joint groove to be welded, automatically aligned the torch and adjusted its height, and also optimized and adjusted the welding parameter corresponding to the measured gap and area. Figure 1 shows the hardware for the longitudinal weld, including the TX/S digital laser camera, the Ez-Trac/P controller, the X-Y slides and the controller, the industrial computer and the I/O controller, and so on.

Currently, the TX/S digital laser camera, which is one of the most advanced laser vision sensors, has a 50 mW visible diode laser inside. The photosensitive device is an advanced digital CMOS image chip. The lateral and height resolutions are 35 and 60 μm, respectively. The highest frame rate is 1 000 frame/s. The digital CMOS sensor made the high speed and flexible image processing possible. The field of interest when processing the profile image removed the effect of the fixture near the groove on image processing and recognition. The high speed and flexible laser sensing system solves the problem of reflection, which causes poor image quality. It was applied steadily and reliably for seam tracking and adaptive welding on a very shiny and burnished aluminum alloy surface. Thus, the application of the sensor should be the basis of acquiring groove geometry for aluminum alloy welding. Figure 2 shows the result of the measurement on the burnished V-groove of the aluminum alloy using the TX/S digital laser vision sensor. The seam tracking point was correctly recognized and the parameters of groove geometry such as the gap, the mismatch and the area were also measured. In contrast, Fig. 3 illustrates the result on the non-burnished V-groove of the aluminum alloy using an analogue laser camera. Disturbed by the reflection, it recognized the wrong tracking point and could not be applied in aluminum welding.

The Ez-Trac/P controller was used to process the image obtained by the laser camera and calculate the geometry parameters of the groove to be welded, such as the groove position, the angle, the gap, the mismatch, the area, and so on. On the one hand, the Ez-Trac/P drove the slides horizontally and vertically according to the groove position and the corresponding angles, therefore, it automatically aligned the torch to the groove and adjusted the torch height. On the other hand, according to the gap, the mismatch and the area, the Ez-Trac/P adjusted the wire feeding rate and the welding current automatically for the online adaptive control with the real-time welding parameters optimization.

The torch and the laser camera were installed on the cross slides, which were controlled by the servo controller and could move horizontally and vertically for the torch alignment and height auto adjustment.

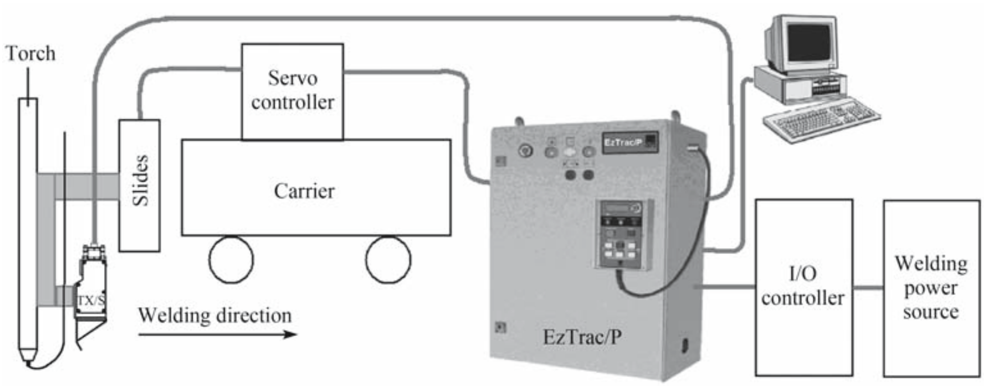

Fig. 1 Schematic laser vision sensing based on adaptive welding system

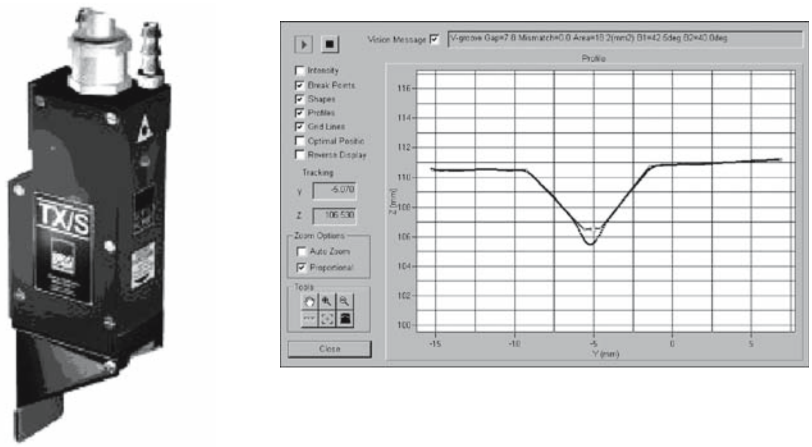

Fig. 2 TX/S digital laser vision sensor and its measurement result on bright burnished V-groove of Al alloy

3) I/O controller and acquisition of process parameters

The I/O controller is the interface for the digital I/O and the analog I/O between the Ez-Trac/P and the welding power source or the servo controller. It controls the welding sequence and also amplifies the analog welding parameter signals. It is isolated and interfaced to the welding power source and the wire feeder.

In the experiment, the acquisition of the welding process parameters was based on the LEM current sensors, the voltage sensor and the data acquisition card (model PCI6023E, NI). The laser sensing parameters were set and adjusted in an industrial computer. The acquired process parameters could be processed and recorded in the computer.

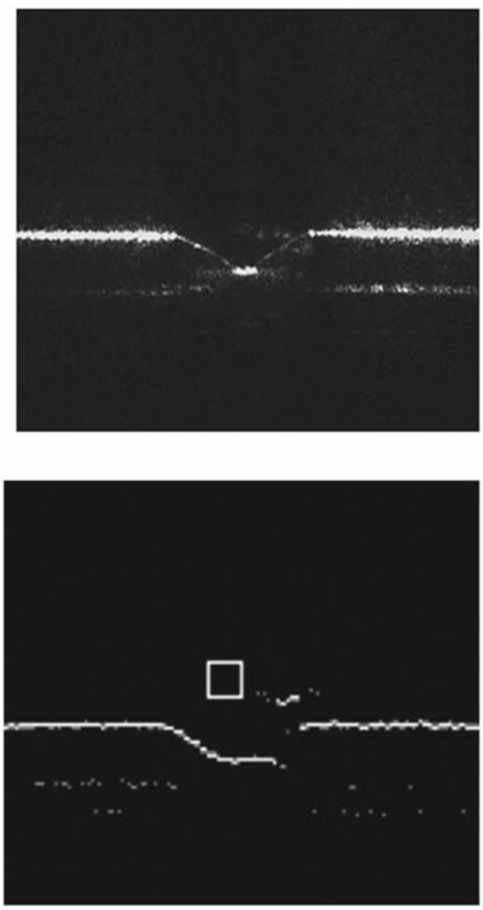

Fig. 3 Image and wrong result on non-burnished V-groove of Al alloy using the other analogue laser vision sensor

3 Acquisition of groove information and inspection before welding

The V-groove, as shown in Fig. 4 (a), is very common in the joints of large-scale aluminum alloy structures in aerospace manufacturing. When the laser strip is projected on the joint, the profile as shown in Fig. 4 (b), would be acquired by the laser camera. After image processing, the coordinates of the break points 0–5, which represent the groove geometry,

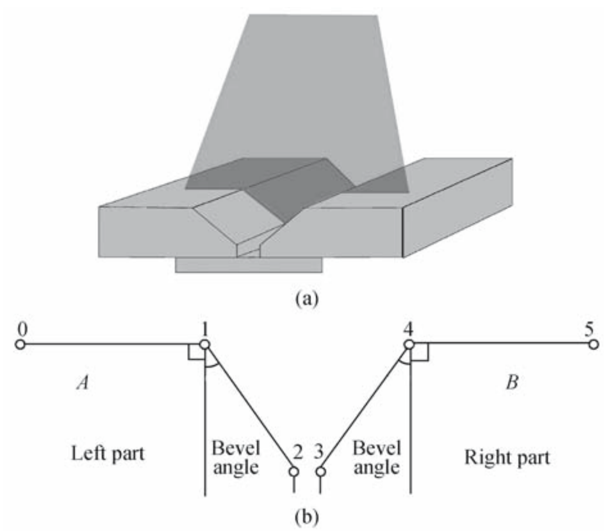

Fig. 4 Weld groove and its laser strip profile feature. (a) Schematic of V-groove with back plate; (b) Profile and break points

were obtained. The tracking point could be defined as the middle of break point 2 and break point 3 or the middle of break point 1and break point 4 according to the groove preparation condition.

In addition to the tracking point, the geometry parameters of the weld groove, which were necessary to improve welding quality, such as the normal of the part surface, the bevel angle, the mismatch, and the area, etc., were calculated from the break points. These geometry parameters were used for the seam tracking and the adaptive welding control and were saved and recorded in a database.

To obtain high quality welding, the parts must be carefully assembled for the desired precise weld groove before welding. When assembling, however, the parts of the large-scale structure, especially for the circumference weld, need to be measured and adjusted several times to ensure that the gap and the mismatch would meet the requirement of the welding process. To monitor and control the assembly quality before welding, the system measured the upper gap, the root gap, the mismatch, the groove area and the other parameters by using the laser camera. Thus, the operator is able to find any improper assembly and correct it manually. The 3D map of a V-groove acquired by the laser camera is illustrated in Fig. 5. Figure 6 shows the measured gap, the mismatch and the groove area.

4 Seam tracking and adaptive control of welding parameter

The slides were driven to move in the Y and the Z directions according to the coordinates of the tracking point calculated by the vision system. Then, the torch would track the seam and keep it at the same height. The seam tracking and the

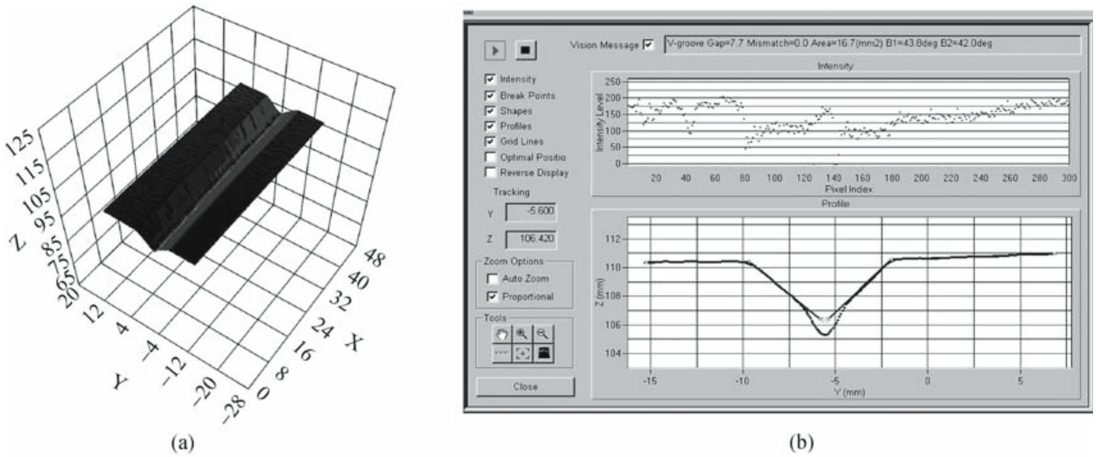

Fig. 5 3D map of a V-groove measured by laser sensor and measurement interface

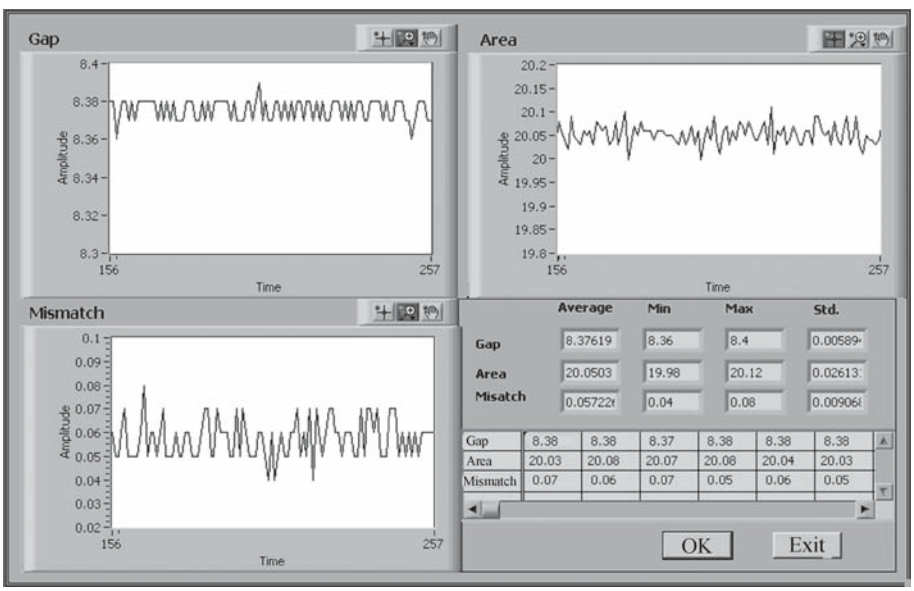

Fig. 6 Interface for measuring gap, area and mismatch of groove

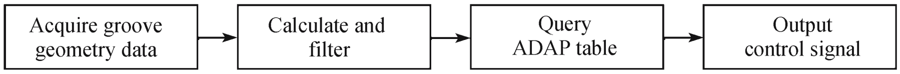

Fig. 7 Diagram of welding parameter adaptive control

torch height control functions sharply reduce the work intensity of the operator. At the same time, the welding quality is improved.

For the large-scale work piece, relatively great absolute errors were found in the groove preparation and the parts assembly. The weld formation should not be uniform if the welding has constant parameters. Previously, the operator had to adjust the welding current and the wire feeding rate, in addition to the *Y* and the *Z* positions of the torch, according to his observation to ensure the uniform weld in a varied groove status. To a great extent, the adjustments mainly depended on the operator's experiments.

When moving, the wire feeding rate is automatically controlled according to the variety of the gap and the area, which were calculated by the adaptive software. The software mainly includes groove geometry extracting, calculating and filtering, querying adaptive table (ADAP table, shown in Table 1), and control signal output. Figure 7 shows the control flow. At first, the adaptive module calculated the groove area according to the geometry data transmitted from the image processing module. Then the calculated area data were filtered by the median filter to remove the invalid data and average the filter to smooth the data. The noise was mostly eliminated. The module queried the ADAP table for the proper welding parameters: the welding current and the wire feeding rate. The corresponding analog signals were outputted to control the power source and the wire feeder. Consequently, the filler metal was properly adjusted to keep the uniform weld. Figure 8 shows a photo of an adaptive welding process. All the welded parts were inspected through the X-ray radiography, the mechanical test and the metallographic examination. The mechanical properties were up to the relative standard (YS0620-97 I class).

Table 1 Adaptive welding parameter table (ADAP table)

Groove area/mm^2	Wire feeder control signal/V	Wire feeding rate/$cm \cdot min^{-1}$	Welding current/A
10	2.2	81.7	340
14	2.3	87.8	342
18	2.4	93.9	344
22	2.5	100.0	346
26	2.6	106.1	348
30	2.7	112.2	350
34	2.8	118.4	352
38	2.9	124.5	354
42	3.0	130.6	356
46	3.1	136.7	358
50	3.2	142.8	360

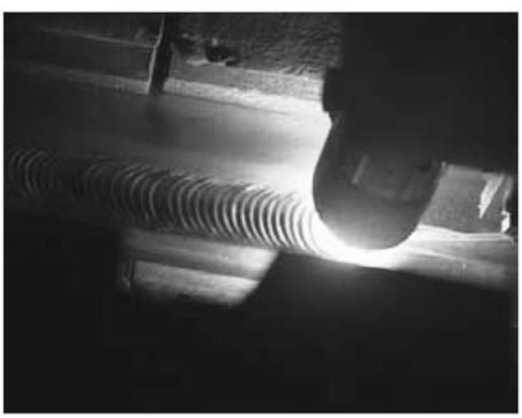

Fig. 8 Photo of adaptive welding process

5 Conclusions

Considering the present conditions and the requirements of TIG welding with wire filling for large-scale aluminum alloy components in aerospace manufacturing, the laser vision sensing technology was applied to precisely measure the geometry of a weld groove. The acquired geometry data, such as the weld bevel angle, the gap, the area, and the mismatch, etc., aided in the assembly of the large parts and their quality control. The automatic seam tracking and the adaptive welding parameter control were achieved in the welding process. The welding quality was good and all the mechanical properties were up to the related standards. In short, the laser vision sensing based on adaptive welding for aluminum alloy should be able to meet the requirements of part formation, groove preparation and assembly of large-scale components. The welding control process was stable. It is worth to extend its application in the manufacture of aluminum aerospace structures.

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