Study on Sensor Design Technique for Real-Time Robotic Welding Tracking System

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Abstract. Based on visual measurement techniques, the real-time robotic welding tracking system achieves real-time adjustment for robotic welding according to the position and shape changes of a workpiece. In system design, the sensor design technique is so important that its performance directly affects the precision and stability of the tracking system. Through initiative visual measurement technology, a camera unit for real-time sampling is built with multiple-strip structured light and a high-performance CMOS image sensor including 1.3 million pixels; to realize real-time data process and transmission, an image process unit is built with FPGA and DSP. Experiments show that the precision of this sensor reaches 0.3mm, and band rate comes up to 10Mbps, which effectively improves robot welding quality. With the development of advanced manufacturing technology, it becomes an inexorable trend to realize the automatic, flexible and intelligent welding product manufacture. With the advantage of interchangeability and reliability, robotic welding can boost productivity, improve work condition, stabilize and guarantee weld quality, and realize welding automation of the short run products [1]. At present, robotic welding has already become the application trend of automatic welding technology. Traditional welding robots are play-back ones, which cannot adapt environment and weld distortion. Especially in the more and more extensive arc-welding course, the deficiency and limitation of play-back welding technology becomes more prominent because of changeable welding condition. It becomes one of the key technology influencing the development of modern robotic welding technology to eliminate or decrease uncertain influence on quality of welding such as changing welding condition etc [2]. Based on visual measuring principle, this text adopts active visual measuring technology, cooperated with high-speed image process and transmission technology to structure a tracking sensor, to realize real-time measurement of the space location and posture information of the work piece and reliable and accurate tracking of the welding seam.

1. Composition of the welding robot system

The composition of the welding robot system is shown as Figure 1. First of all, the setting and display unit sends the data, such as welding seam form, image processing parameters, sensor parameter, etc, through RS485 bus to the central processing unit, then the central processing unit controls the visual sensor to work through Ethernet according to these parameters; next, the visual sensor gathers the information, such as welding seam shape and relative posture of the welding head towards welding seam, etc, and transmits the data to the central controller in real time through Ethernet; after that, the central controller calculates out the position compensation of the welding head relative to the welding seam according to the receiving data, and transmits the error control and basic order to the robot controller through Ethernet or serial port. Finally, the robot controller guides the head to realize real-
time tracking of welding seam according to the compensation [3]. In the system, the visual sensor is a key part, which influences the performance of the system directly.

2. Design of the visual sensor
In light of the operation principle of the welding robot system, the visual sensor needs to meet the following demands: The image information gathered by the visual sensor can reflect that the relative position between the head and welding seam, so that the central processor can get the motion compensation of the head relative to welding seam according to the information; the visual sensor needs to keep high sampling rate and data transmission rate to guarantee that the head can obtain compensation information from central processor in very short displacement; in terms of actual request of the head, the focus of optical system in visual sensor should be about 100mm, the depth of field is 40mm, and the whole precision reaches 0.3mm.

According to above-mentioned requests, the vision sensor adopts the way to be fixed on the welding head and follows the head to reflect the real-time position relation between the head and welding seam in the course of welding. The design of the visual sensor is divided into two parts, an image sampling unit and a image processing unit. The former is responsible for gathering the image information of the welding area in real time, and the latter finishes high-speed processing and transmitting of the gathered data.

![Figure 1. welding robot system diagram.](image)

2.1. Image sampling unit
Measure principle diagram is shown as Figure 2. The measurement part mainly composes of electrical machinery, reflecting prism, laser instrument, linear CCD and coded disk. The sensor is installed on the work piece end of the robot, and a regular relation exists with the coordinates of the machine, which can be calibrated ahead of time. A point light source illuminates the work piece through reflecting prism, and the reflected light is received by linear CCD through reflecting prism, which makes up the triangulation. The position relation between laser instrument and linear CCD is fixed and can be calibrated ahead of time. Thus the depth information of welding seam can be calculated out according to the position of light spot on linear CCD. In the meantime, the angle value of the coded disk is read so that the coordinate of the light spot on welding seam can be calculated out under the sensor coordinate; the position relation between the sensor coordinate and the tool coordinate so that the coordinate of this spot also can be figured out under the tool coordinate. The electrical machinery drives the prism and the coded disk to turn, so that the light spot will scan the whole welding seam section and the space coordinates of spots on the whole section can be calculated out; the robot drives the visual sensor to move along the welding seam. As a result, multiple welding seams sections make up the three-dimensional spatial appearance of welding seam, and the measurement is finished.
2.2. Image processing unit

Fast speed of measurement is needed to realize real-time guidance in the course of welding, thus image processing speed becomes the key influence on the speed of measuring.

In the dotted line frame of Figure 3 is a principle diagram of high-speed image processing unit of this system, it adopts a FPGA chip to control an A/D chip to gather analog signal from image sampling unit, carries on FIR digital filter to the data, and stores the result in Block RAM within FPGA. Afterwards, DSP is utilized to deal with the advanced image algorithm to the stored data. Finally, the high-speed data transmission of 10Mbps is realized, cooperated with Ethernet interface chip to structure TCP/IP interface.

3. Image process algorithms

3.1. Digital filter

Because of complicated environment and much interference in industry field, it is unavoidable to introduce interference in the course of image sampling and transmission, which will influence the following image processing, so image processing unit should carry on digital filter to the input signal to eliminate high-frequency interference.

The sensor of image processing unit is linear CCD. It gathers reflected light-spot from welding seam, and outputs 2048 effective elements in each frame. Because the output values of 50–60 elements covered by reflected light-spot will increase obviously, the output picture of a frame appears to be a narrow positive pulse. If the signal is interfered, there will be some burrs at the rising edge and
the descending edge of the positive pulse in the output picture, as Figure 4 shows. It is clear that the interference shows as a high-frequency pulse which is not in the same frequency band with the effective signal, so the interference can be eliminated through low-pass digital filter to the output signal after A/D converter, as Figure 5 shows.

This system adopts FIR (finite impulse response) filter algorithm, and its filter parameters are designed as follows:

Input sampling frequency is 40800Hz, input transition frequency is 1080Hz, exponent number is 20, window function is Hamming, and its frequency characteristic is as Figure 6 shows.

3.2. Trick recognition
Image processing unit needs to get the centre position of the light-spot in each frame, so the area where the light-spot covers should be recognized at first. According to the picture that CCD outputs actually, the output values of CCD elements corresponding to the light-spot are larger than the others. Through choosing certain threshold value for screen, the area covered by the light-spot can be figured out, thus its centre position is obtainable.

This system adopts floating threshold value. Firstly, the data in the first frame is scanned, and its maximum is recorded. Then, half of the maximums is regarded as threshold value, and the following sampled data are recognized on a basis of this threshold value to calculate out the centre position of the light-spot.
4. Experimental results and data analysis

4.1. Experiment method
The experiment targets are a set of V-slot standard gauges, whose width and depth is formed by a series of standard values, divided into 10mm, 15mm, 20mm and 25mm four groups. First of all, one gauge is fixed on the measuring table. The measuring table has been regulated accurately so that the V-slot of the gauge is within the range of the visual sensor, and roughly lies in the centre of visual field. Through calibrating the position and the posture of the gauge, the relation between the gauge and the visual sensor is obtained. In the experiment course, the position and posture of gauges must remain the same.

In the course of experiment, the visual sensor samples many times five different positions of the V-slot at the same time, in order to obtain the width and the depth information. Afterwards, the other three gauges are sampled under the same experiment condition sequentially.

4.2. Experimental result
The sampled raw data pass through a series of algorithms, such as filter, trick recognition and transfer of axe, etc, and the geometric size of the V-slot is drawn. Table 1 has listed the measurement value of four groups of widths and depths, which refer to the maximums and minimums of the depth and width of the above-mentioned four groups of V-slots respectively.

| V-slots (Standard) | width (maximum) | width (minimum) | Depth (maximum) | Depth (minimum) |
|--------------------|-----------------|-----------------|-----------------|-----------------|
| 10mm               | 10.194mm        | 9.864mm         | 10.251mm        | 9.812mm         |
| 15mm               | 15.165mm        | 14.855mm        | 15.241mm        | 14.798mm        |
| 20mm               | 20.148mm        | 19.841mm        | 20.237mm        | 19.805mm        |
| 25mm               | 25.168mm        | 24.873mm        | 25.248mm        | 24.817mm        |

4.3. Result analysis
In order to test the whole system in the precision of measurement of the width and depth direction, the width and depth of V-slots are tested respectively. It can be found out from the result of table 1, that the precision of the whole measuring system reaches 0.3mm both in the width direction and in the depth direction.

In addition, the system is obviously more precise in width direction than in the depth direction. It is because the depth information is obtained through the triangulation, but the surface characteristic of the targets has certain influence on output of the sensor. Besides, the object with better reflectivity has better measurement precision, and the object with worse reflectivity has worse measurement precision. And the roughness of surface, inconsistent geometry form and color will bring a certain influence too [8]. The surface of measurement targets is very smooth and reflects well. Because of the geometric form of V-slots, the scattering light becomes weak and not even, which have influenced the system in the precision of measurement of the depth direction.

5. Conclusion
Based on visual measuring principle, this text adopts active visual measuring technology, cooperates with high-speed image processing and transmission technology to structure a visual tracking sensor. This sensor can realize real-time measurement of the space location and appearance information of the work piece, and guide robots to track welding seams reliably and accurately in real time.
The working distance of the visual sensor is 100mm, and the measuring range in depth direction is 40mm. The measuring speed of the visual sensor reaches 10000 spots per second, and the data transmission rate reaches 10Mbps.

FPGA is utilized to realize high-speed data sampling and storage control, and DSP is used to analyze and process the data, and Ethernet interface chip is cooperated to structure TCP/IP interface, and finally real-time image sampling, processing and transmission are realized successfully.

The measurement precision of the whole system is superior to 0.3mm, which is important to lead the welding robot to track the welding seam and improve the quality of welding.

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