A VISION SYSTEM IN ROBOTIC WELDING

Absi Alfaro, S. C[1]

[1]Department of Mechanical Engineering, GRACO, the Brasilia University,
Brasilia, DF, Brazil – 70.910-900, sadek@unb.br.

ABSTRACT

The Automation and Control Group at the University of Brasilia is developing an automatic welding station based on an industrial robot and a controllable welding machine. Several techniques were applied in order to improve the quality of the welding joints. This paper deals with the implementation of a laser-based computer vision system to guide the robotic manipulator during the welding process. Currently the robot is taught to follow a prescribed trajectory which is recorded a repeated over and over relying on the repeatability specification from the robot manufacturer. The objective of the computer vision system is monitoring the actual trajectory followed by the welding torch and to evaluate deviations from the desired trajectory. The position errors then being transfer to a control algorithm in order to actuate the robotic manipulator and cancel the trajectory errors. The computer vision systems consists of a CCD camera attached to the welding torch, a laser-emitting diode circuit, a PC computer-based frame grabber card, and a computer vision algorithm. The laser circuit establishes a sharp luminous reference line which images are captured through the video camera. The raw image data is then digitized and stored in the frame grabber card for further processing using specifically written algorithms. These image-processing algorithms give the actual welding path, the relative position between the pieces and the required corrections. Two case studies are considered: the first is the joining of two flat metal pieces; and the second is concerned with joining a cylindrical-shape piece to a flat surface. An implementation of this computer vision system using parallel computer processing is being studied.

KEYWORDS

Vision system, robot welding cell, parallel computer processing.

1. Introduction

At the University of Brasilia a robotic welding station was implemented, it consists of a robot manipulator (ABB IRB200), a welding machine (Migatronics BDH320) and a computer supervision system (PC computer). The current procedure is: define a welding task [1,2]; fix the work pieces; and determine the welding path. The robot is then taught to follow the prescribed trajectory which is recorded and repeated over and over relying on the repeatability specification from the robot manufacturer. The objective of the proposed vision scheme is to determine trajectory deviations from the reference trajectory and sending this information directly to the robot controller for automatic path following. The paper begins with the description of the vision sensing system, then the interesting image features are defined and mathematically characterized. Next, an algorithm for image processing to determine a reference trajectory is proposed and experiments described. Finally, considerations to implement visual servo control strategies are discussed.

2. Vision Sensing System

The vision sensing system consists of: a) laser-emitting diode circuit: 40mW power, 693.9nm wavelength, cylindrical lens to produce a structured-light plane; b) CCD camera: high resolution 725 (H) x 582 (V), 625 lines; c) a PC video frame grabber card: 4MB memory, 8 bit resolution; and d) a computer vision algorithm. The laser device and the camera are rigidly fixed to the robot end-effector which carries the welding torch as shown in Fig.1. The laser light plane projects onto the workpieces and a laser stripe perpendicular to the weld path forms, the stripe being in the intersection of the weld plane and the light plane. The frame grabber then digitizes and stores the image data for further processing.

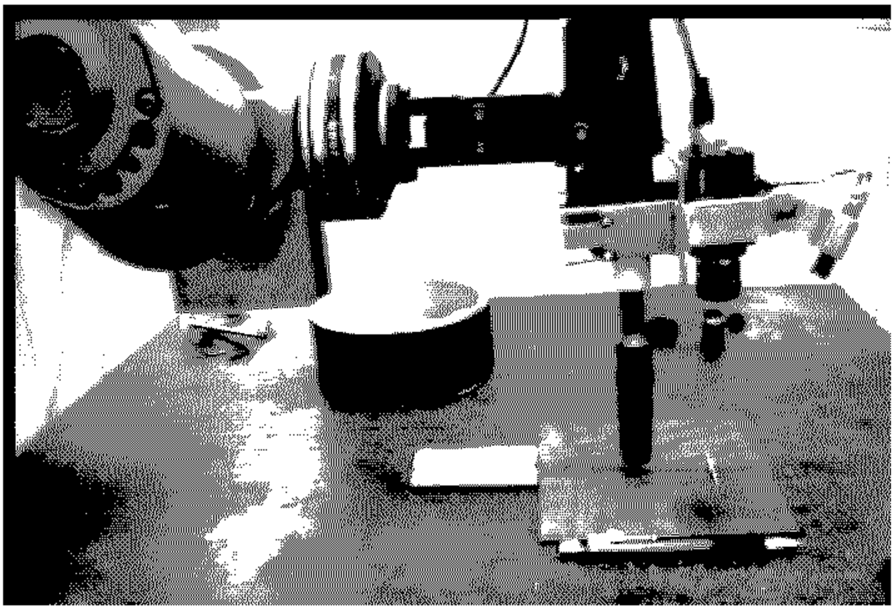

Fig. 1 Vision Sensing System

3. Problem Statement and Image Features Definition

The first problem being considered is welding two flat adjacent plates. The gap between these two plates will become the welding path, being then the reference path for the torch guidance system. Finally, the problem of non flat plates will be discussed. The geometry and variables of the vision sensing systems under study are shown in Fig.2.

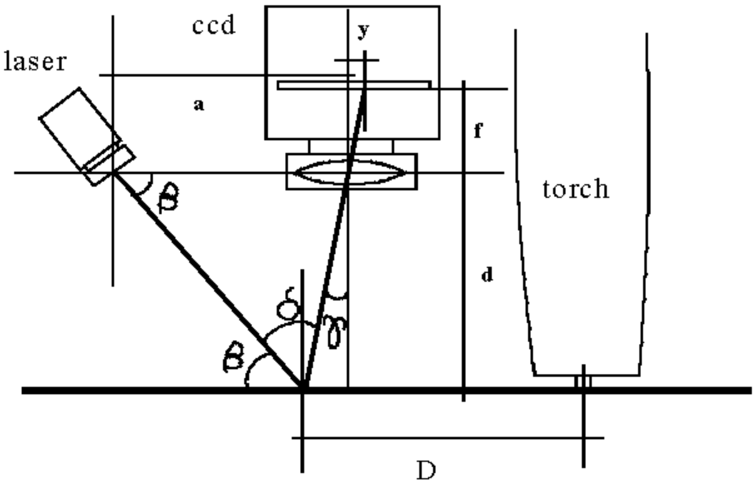

Fig. 2 Vision Sensing System arrangement

The image processing algorithm relies on analysis of the reflected light (a laser stripe) from the workpieces. The gap between the plates will disrupt the laser stripe. The camera acquires this disrupted stripe image and converts it into a digital gray-scale matrix by means of the frame grabber. Fig.3 shows the laser stripe image for two adjacent plates. In case of non flat plates the stripe will bend at the disruption gap. The digital gray-scale matrix is stored on the frame grabber memory as a matrix of picture elements (pixels). As each pixel is represented by a 8-bit digital word, there are 256 gray levels: 0 represents black and 255 white. The algorithm will identify pixels by their gray levels and matrix-element index. The matrix index indicates the pixel position on the Cartesian coordinates (x, y) with the origin at the upper-left corner of the image plane [3].

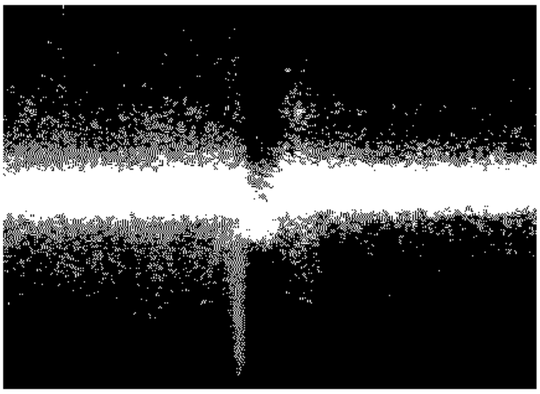

Fig. 3 Laser Stripe Image for two flat work pieces

Depending upon the arrangement of the elements of the vision sensing system (Fig.2) the laser stripes will be of different widths. The image processing algorithm calculates the gradient of the digital image matrix in order to detect the edges of the laser stripe. The mathematical characterization of the stripe is the equation of a straight line $y = a.x + b$, these parameters a and b will then define the laser stripe image.

4. Image Processing Algorithm

Laser Stripe Image Parameter Identification - For a non flat case, Fig.4 shows the image plane with the disrupted and bent stripe together with a searching window for the left-side plate. A searching window is initially defined for each plate on the image plane. The window has dimensions winx and winy, along the respective coordinate axis with the origin at the (x0, y0) point. The window is then divided into N-1 vertical zones of fixed-width winx/(N-1), where N is the number of points used to represent the laser stripe image. The first point is determined by: 1) scanning a vertical line from (x0, y0) downwards for an abrupt change of gray-level gradient in order to find the upper edge of the stripe; and 2) scanning a vertical line from (x0, y0 + winy) upwards to find the stripe lower edge. These two points define a segment across the stripe, to represent the stripe along the scanned line a mid-point is then calculated as the average of these two points. The N-1 points that remains are determined in this way: 1) stepping to the right; 2) scanning for the edges of the stripe along a shorter line centered at the (yi-1, xi) point; 3) locating the i th mid-point.

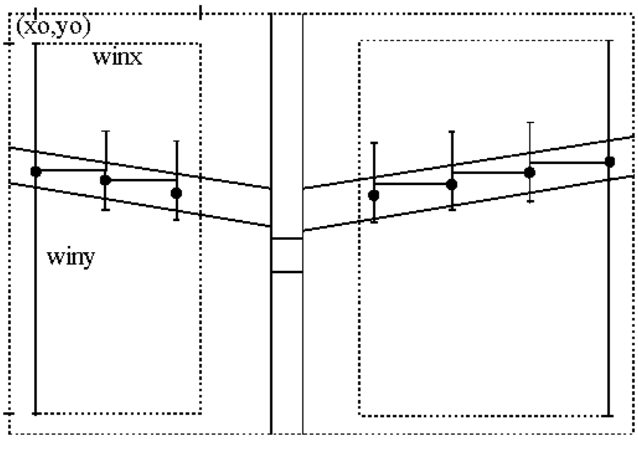

Fig. 4 Determination of mid-points on laser stripe image

By using a least square curve fitting method over the sequence of mid-points it is possible to fit a straight line and identify the aL and bL parameters which will represent mathematically the laser stripe. Lets call this line the left laser line. The algorithm applies a similar procedure for the right-side plate locating the mid-points from the right to the left and identifying the respective aR and bR parameters. Thus, the left and right laser lines will be the mathematical models of the left-side and right-side of the laser stripe respectively.

$$y = a_L . x + b_L \quad (1)$$

$$y = a_R . x + b_R \quad (2)$$

Reference Path Identification for Guidance Purposes. This part of the algorithm locates the gap between the plates processing the image plane. By searching along the laser lines for abrupt changes of gray-levels the gap coordinates are determined. The algorithm scans the image along the line defined in (1) in order to locate the left edge of the gap; a second search along (2) will determine the right edge. These points define a segment across the gap, then the average of them will determine a mid-point. The sequence of these mid-points will constitute the gap line, a mathematical representation of the physical gap. The gap line will become the welding path or the reference trajectory for robot guidance purposes. The algorithm works well as far as a gap exists.

5. Image features in case of non flat workpieces

For non flat plates there is an alternate procedure to determine the gap line. It relies on the fact that, in this case, there is an intersection between the laser lines, represented by equations (1) and (2), and this intersection will be at the gap. Also, in this case, additional image features are available to guide the torch. It is possible, for example, to modify not only the torch translation in reference to the gap line, but also the torch orientation in reference to the workpieces. Referring to Fig. 5, lets assume the right-hand

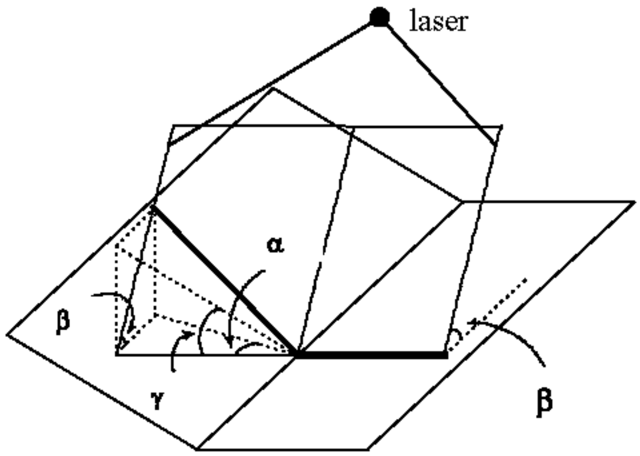

Fig. 5 Determination of orientation of workpieces.

plate is in a plane orthogonal to the camera axis (reference plane) and the torch is traveling along the gap line, it is easy to show that γ, the elevation angle of the left-side plate, is given by:

$$\gamma = \tan^{-1}[(\tan\alpha).(\tan\beta)] \quad (3)$$

where α = tan-1(aL) is the slope of the left laser line and aL is the parameter obtained during the image processing algorithm. β is the angle between the laser beam plane and the reference plane. These image features can then be processed to obtain the torch orientation in yaw and roll coordinates. In particular the yaw angle represents the axis of the torch relative to the workpieces and the roll angle will be an additional information for tracking the gap line.

6. Implementation of a Visual Servo Control for Welding Processes

Torch guidance is implemented by calculating the coordinates of the trajectory deviation between the reference trajectory and the torch path. The reference trajectory results from the image processing algorithm as either the gap line or from the sequence of intersection points of the laser lines (non flat case). The vision sensing computer transfers the trajectory deviation relative to the torch coordinates to the robot controller through a serial communication link. It uses the computer link, a computer language protocol from the robot manufacturer. A parallel communication link was also implemented for controlling the data transfer process between the vision sensing computer and the robot controller.

As shown in Fig. 4, the image plane model has a left window, a gap and a right window. Being the torch exactly over the welding path the gap image should be at the center of the display. The algorithm displays a centered vertical line for reference and calculates the trajectory deviation, that will be transferred to the robot controller. The gap image displays sideways over the laser stripe and the algorithm adjusts the windows size to avoid image overlapping. Experimental tests were performed using arbitrary welding paths and the guidance scheme proved to be adequate.

7. Strategy of Tasks Processing and Distribution

The main difficulties found for the welding robot's information processing guided by sensors are:

- fast contrast changes,
- scattering weld,
- complexity of the image processing,
- need to obtain the position of the junction with high reliability.

Among captured images (each 60ms), the contrast can vary considerably. This makes unfeasible the use of fixed values or previous gray threshold levels. The welding process can be unstable and in this case to produce scattering random liquid metal ejected from the fusion zone. The sensor and the algorithm should, therefore, be highly immune to scattering. To obtain the information on the weld geometry and the welding paths, a series of complex operations need to be accomplished in real time. This, in general way, cannot be satisfied by computers conventional architectures. Consequently, the processing strategy was conceived to explore the maximum parallelization potential of transputers links. The figure 6 shows the tasks distribution of transputer net.

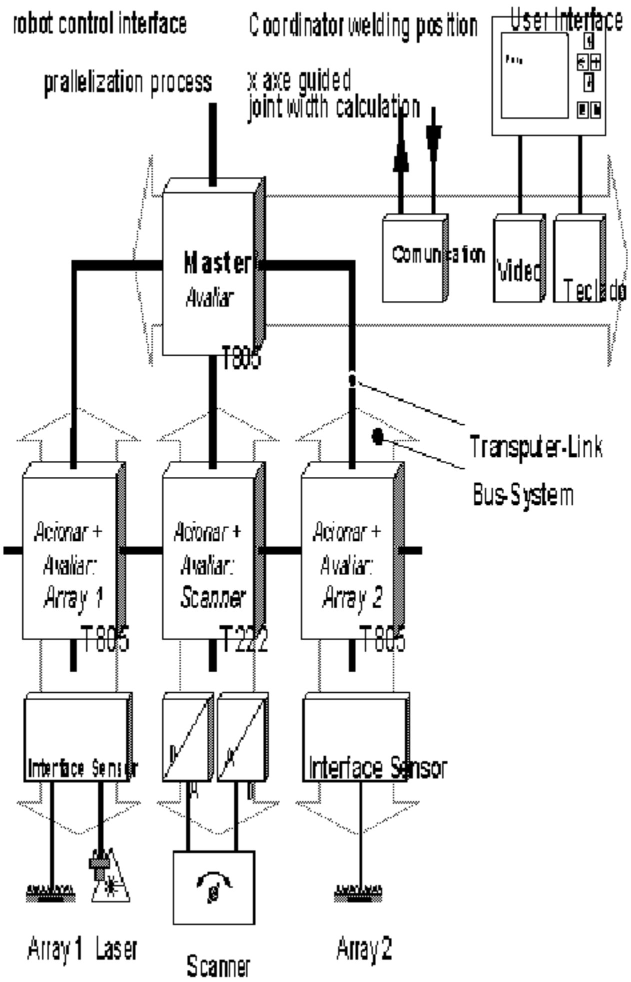

Fig. 6. Distribution tasks among transputers net.

8. Conclusions

The proposed computer vision scheme consists of a laser-emitting diode, a CCD camera, a frame grabber card, host computer and an image processing algorithm. This vision scheme performed adequately during the experimental tests and constitutes a first step to implement a full visual servo control for the robotic welding station [4]. Some problems related to smooth robot arm movements during trajectory corrections must be considered. One alternative is to write reference signals directly to the individual joint controllers. Experiments also shown that vision-based control in welding process must be flexible in order to cope with a variety of welding tasks and available equipment.

Currently, a specific strategy to implement a visual servo control including the overall system kinematics and dynamics is underway. Provisions to filter out the image noise caused by the arc light and radiation from the hot metal by using a narrow-band optical filter are under study [1]. Executing algorithms in real-time mode will demand parallel processing, then a transputer system is being implemented.

Acknowledgements

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