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Adaptive robotic welding using a rapid image pre-processor

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Abstract

The rapid pre-processor initially developed by NRCC and Leigh Instruments Inc. as part of the visual aid system of the space shuttle arm [1] has been adapted to perform real time seam tracking of multipass butt weld and other adaptive welding functions.

The weld preparation profile is first enhanced by a projected laser target formed by a line and dots. A standard TV camera is used to observe the target image at an angle. Displacement and distorsion of the target image on a monitor are simple functions of the preparation surface distance and shape respectively.

Using the video signal, the pre-processor computes in real time the area and first moments of the white level figure contained within four independent rectangular windows in the field of view of the camera. The shape, size, and position of each window can be changed dynamically for each successive image at the standard 30 images/sec rate, in order to track some target image singularities. Visual sensing and welding are done simultaneously.

As an example, it is shown that thin sheet metal welding can be automated using a single window for seam tracking, gap width measurement and torch height estimation. Using a second window, measurement of sheet misalignment and their orientation in space were also achieved. The system can be used at welding speed of up to 1 m/min. Simplicity, speed and effectiveness are the main advantages of this system.

1. Introduction

One of the ways to improve the quality of the welds made through robotic welding is to make real time modifications of the programmed path and of the welding parameters in order to insure that the joint location electrode coordinates relationship, as well as the welding parameters are always optimized. Mismatch between electrode tip coordinates and joint coordinates may occur because of the cumulative imprecisions due to path reproducibility; inadequacy of the programmed path because the visual estimation and positioning made by a human operator may not always be optimized; and tolerances associated with cutting, shaping, jigging and positioning of the parts to be welded. In addition, the inevitable dynamic distortions associated with the process increase the mismatch. These cumulative imprecisions also lead to gap size variations requiring mass balance adjustments in terms of filler metal additions. Altogether, these conditions may lead to improper weld geometries.

In order to incorporate real time modifications of the program fed into an automated welding station, real time sensing of the relevant weld area characteristics has to be achieved. In simplified terms, these charasteristics are joint axis coordinates, gap size in butt welds, pool geometry, and pool location with respect to the joint axis. Since these characteristics are rather simple geometrical features whose space coordinates become of relevant significance to improve the welding operation, artificial vision thus appears to be an essential tool for adaptive welding.

2. Vision applied to welding

2.1 General. The analysis of the image made by the intersection of a plane of light and a weld preparation has been the basic approach for seam location recognition. Adaptive functions such as seam tracking has been achieved through this scheme. [2-4] In many applications, a "learn run" is first done and characteristics such as joint axis coordinates and gap size if any, are stored. Then the weld is made and the electrode coordinates and welding parameters are varied continuously to cope with the information

stored during the "learn run". [5] The disadvantages of that approach lie in the reduced duty cycle of the machine because of the "learn run", and in the small differences that exist between the joint location and gap size memorized during the run, and those that exist during the welding operation. These differences are due to the inevitable distorsions and thermal expansions bound to the process.

In other cases, real time seam tracking is achieved, particularly when the joint location is revealed by a rather simple image such as in butt welding thin metal sheet. [6] Figure 1 shows the rather simple image made through the intersection of a plane of light with the gap.

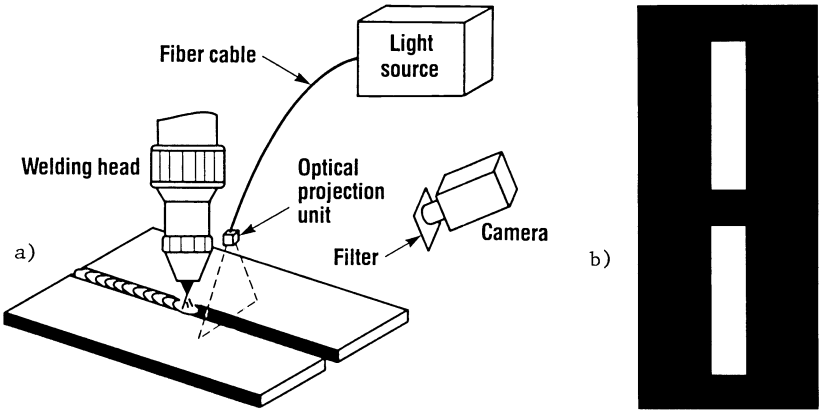


Figure 1 Intersection of a plane of light with the gap to be weld (a) and its image viewed from the camera displayed on a monitor (b).

However, in the most common cases where a J or V groove preparation is present, and where multipass welds are required, there is not, to our knowledge, an operational multifunction sensing device able to perform real time seam tracking and pool geometry and location control. One of the difficulties preventing such occurrence is the rapid processing time required to cope with the trends of the welding discipline that pushes towards high welding speed, and the rather complex profile generated by multipass welds. Pulse GMAW systems now invading the area coupled to improved weld metal alloys may well raise the upper welding travelling speed in excess of 1 m/min. At those travelling speeds and with the requirement of corrective action every 0,5 mm, processing time of the order of 30 ms must be achieved.

2.2 NRCC Approach. In order to cope with the processing time requirements imposed by the welding technology and the complex shape of multipass preparation, the approach used at NRCC (IMRI) has been to reduce the number of relevant features in the image from which significant and sufficient information can be obtained and used to perform the welding adaptive functions, even for the complex preparation used for multipass welds. A modular pre-processor whereby each module is dedicated to a given feature has thus been used to incorporate vision to welding systems. The pre-processor is based on a joint development made by the National Aeronautical Establishment of the NRCC and Leigh Instruments Corporation. It works with a standard NTSC camera and was first aimed at being a visual aid to the Canadarm manipulation from the NASA Space Shuttle. Each pre-processor module functions are as follow: a) the obtention of a binary image, using a preselected threshold contained within a dynamically programmable rectangular window covering a small portion of the field of view, and b) the determination of the area and of the first moment of the white level feature within the window. Image coordinates, and through simple triangulation, space coordinates of a selected feature within the field of view, are thus obtained at a rate of 30 time/s. By cleverly selecting a number of relevant features in the image made by the intersecton of a plane of light and a weld preparation, and by properly treating the expected relatioships between these features, adaptive functions

such as seam tracking a variety of weld geometries including multipass ones can be performed. It is into this modular approach that lies the interest of the vision system for welding developed at NRCC (IMRI). It can cope with welding travelling speed requirement trends by using rather simple and proven technology.

3. Description of NRCC (IMRI) vision and of its function applied to welding

3.1 Generalities. Figure 2 shows the block diagram of the vision system developed at IMRI. As most systems, it is made out of a projection unit, and a receiver unit. The optical axis of both units are at angle so that triangulation can be performed either through a calibration procedure or from knowledge of the optical characteristics of the systems.

The camera image is fed into the pre-processor modules that provide area and first moments of individually selected features of the image. The microprocessor carries out logical and mathematical operations to drive the torch coordinates, change the welding parameters, and window locations in the field of view. The window locks on the selected feature, with an imposed relationship between its center and the centroid of the feature.

3.2 Particularities. At the transmitting end, the plane of light is projected normally onto the work piece. An HeNe Laser coupled to a bundle of optical fibers, to a cylindrical lens and to an objective provide a pseudo-rectangular light beam whose intersection with a surface normal to the optical axis at the focal point of the objective makes the profile highly visible and measurable.

At the receiver end (camera), a narrow band filter tuned to the HeNe laser wavelength is incorporated into the optical axis in order to improve the signal to noise ratio and to minimize arc interference.

In some simple cases, because the gap size is computed from the white level area of a feature, the line width has to be constant over its useful length in order to minimize errors in gap size calculation. A new line forming device is actually under development in order to achieve a more uniform distribution of constant light intensity. The optical system must also provide sufficient depth of field to maintain a good precision on gap size calculation when the plates are slightly misaligned. With a 75 mm objective, the pixel size is approximately 0,1 mm. Using a zoom system increases the precision of measurement in the plane of the weld but decreases the depth of field and therefore may lead to increase gap size and gap centers errors if there is a mismatch between the plates. (See section 3.3.1)

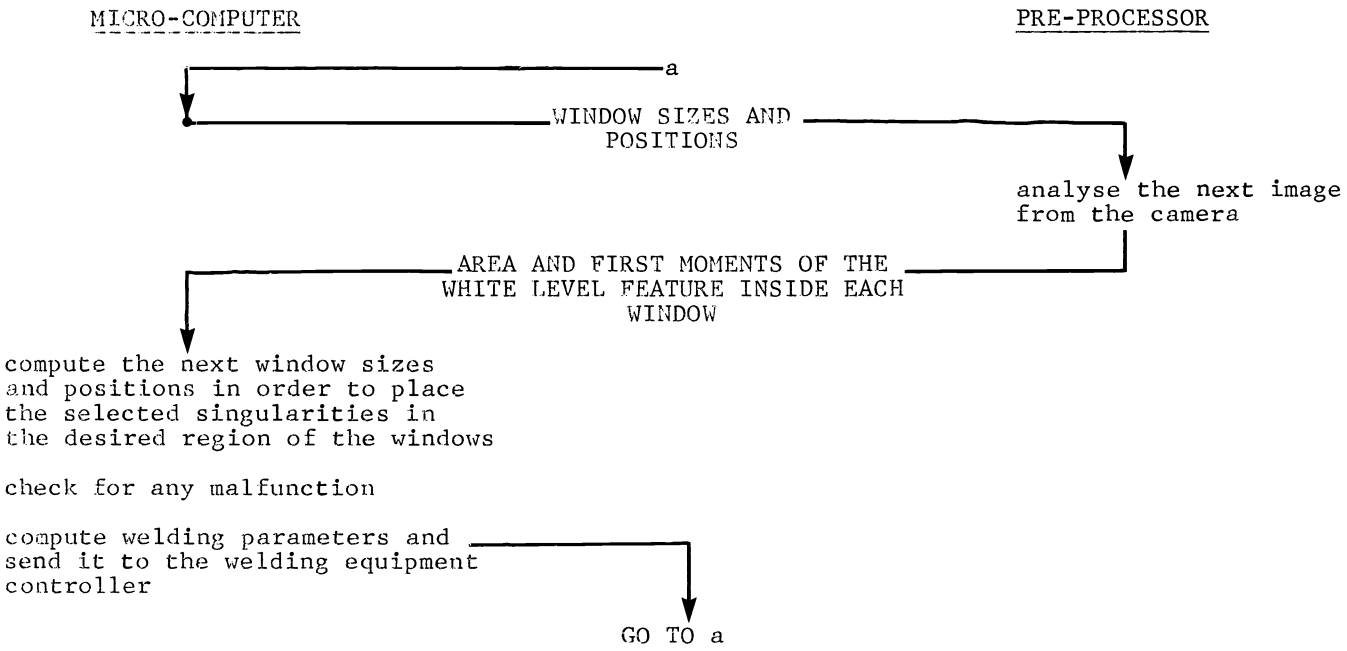
Because given relationships may be imposed between the centroid of the selected feature and the center of the window, line segments at angle may be tracked and the coordinates of their intersection estimated. Figure 3 illustrates how the intersection of two line segments can be tracked by imposing a set of conditions on the centroid location and on the area of the feature. This set of imposed conditions will always maintained a feature such as the lower right hand portion of a multipass weld within the window. The intersection of the segments can thus be estimated as the mid point between the centroid of the feature and the center of the window. By properly selecting window size, precision of 1 mm may be achieve and this is usually satisfactory for multipass weld seam tracking.

Search for a lost feature. If for any reason, the feature appearing in a window no longer comply with the selected set of criteria describing it, then an algorithm is built into the control software whereby a search for the proper feature is initiated. If after 0,5 s, it can not be found, then an alarm is turned on and the system turned off while the operator looks for a malfunction.

3.3 Application to welding. Because the vision system is made of modules each dedicated to a given feature, simple operations can be accomodated by only one module whereby additional ones are required whenever the complexity of the adaptive functions increases. We will show on the following paragraphs how the system can be used for a variety of situations.

COMPUTER AND PRE-PROCESSOR COMMUNICATION

BLOCK DIAGRAM



HARDWARE BLOCK DIAGRAM

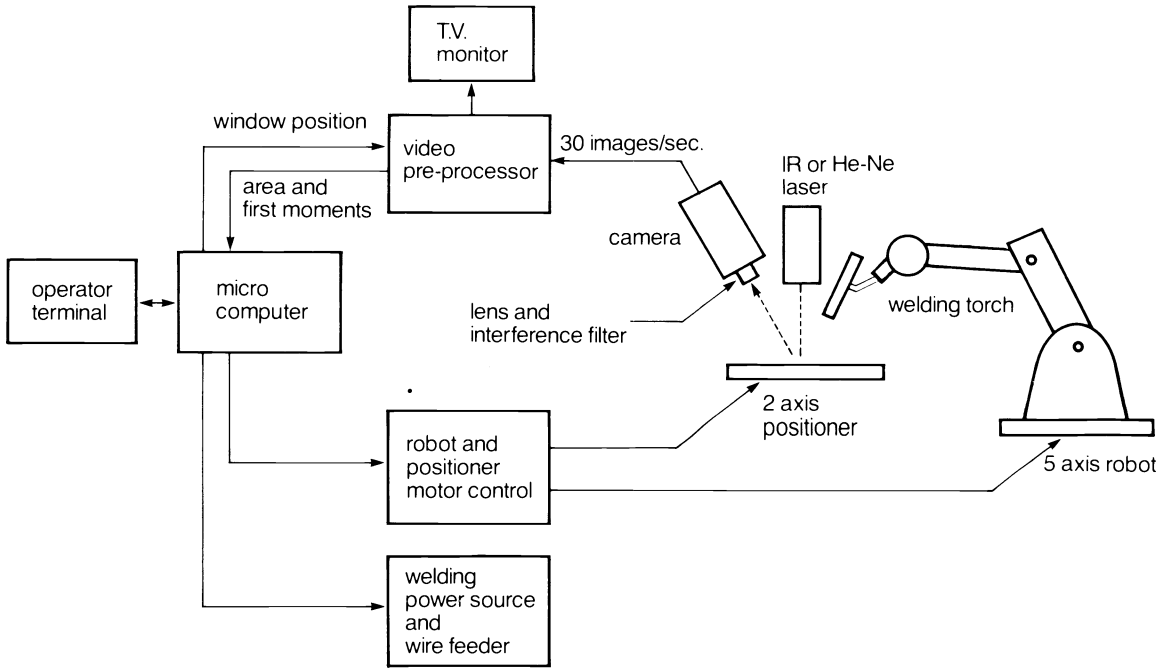
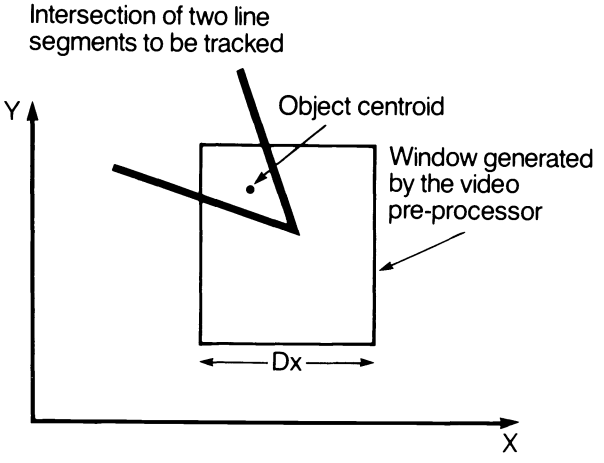


Figure 2 Vision system for welding robot.

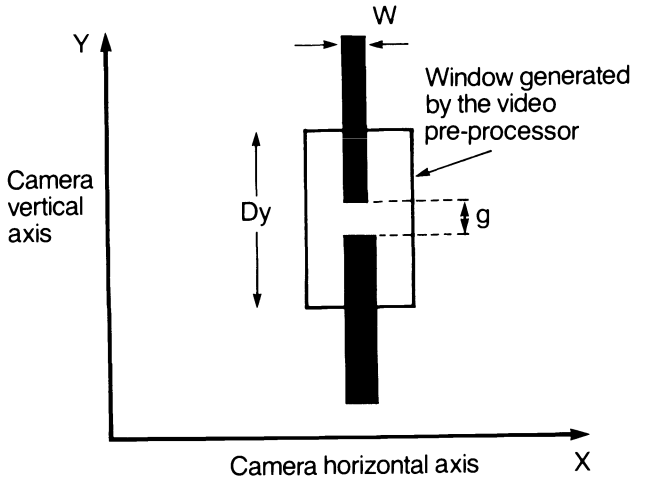


Tracking conditions for this example:

1. object centroid should be maintained in the upper left corner of the window
2. $\frac{A}{Wo} > \frac{Dx\sqrt{2}}{4}$

where A is measured object area and Wo is the calibrated width of the line segments.

Figure 3 Tracking of the intersection of two line segments by the imposition of a set of conditions on the centroid location and on the area of the object in the window.



Pre-processor outputs:

A: area of the video white level surface inside the window
Cx, Cy: Centroid of the white level surface

Then:

$$g = Ko\,(Wo\,Dy - A) / Wo$$
$$h = K1\,cx$$
$$p = K2\,\left(\frac{Dy^2}{2} - \frac{Cy\,A}{Wo}\right) / g$$

where:

Ko, K1, K2	are constant related to the objective focal length
Wo	is the calibrated thickness of the line
Dy	is the vertical size of the window
g, h, p	are respectively the size, height and lateral position of the gap
w	is the actual line thickness

Figure 4 Gap tracking for butt welding thin metal sheet.

3.3.1 Butt welding thin metal sheet. A single module in that case can be used for providing information on seam coordinates and gap size. Figure 4 shows how to handle the situation with one window. The gap corresponds to the " hole" in the enclosed line. The " hole" centroid is related to the white level figure centroid which is a direct output of the pre-processor. Any lateral displacement of the gap shift the " hole" centroid in the y direction. The gap size is computed from the white level area, substracted from the area of an ideal full line of constant width. In addition to the lateral position of the gap, obtained from the " hole" centroid, the vertical distance between the torch and the plates can also be obtained. It is related to the x coordinates of the centroid.

Line width variations are observed when the surface gets out of the focus plane. This situation may occur when the plate misalignment is large. When a single module is used, it will result in imprecisions in gap size and position. Figue 5 illustrates the difference between actual gap axis and computed one when the plate misalignment is relatively large.

3.3.2 Use of 2 modules for seam tracking butt welds. A butt weld can also be tracked by 2 modules as Figure 6 shows. In this case, each module becomes an edge follower. The additional information obtained through this scheme is the vertical mismatch between the plates as given by the differences in the x coordinates of each edge. By imposing the location of the centroid to be half way in the lower part for the bottom window, edges are at each window center . Gap centers is half way between window centers and gap size is related to the difference in the window center y coordinates. The system is then no longer affected by an out of focus situation.

3.3.3 Multipass welds. A variety of useful information can be obtained by using 4 modules to analyze a weld preparation of the V type. Figure 7 shows how each module tracks the edge at the bottom and at the top of the preparation. The edges are recognized from the criteria described before (Figure 3) about the localisation of the intersection between two line segments. Their coordinates are estimated from the mid point between centroids and window centers; gap sizes are then calculated from the differences between edges coordinates. As the number of pass increases, gap size increases and orders may be given to the system to change the welding parameters in order to comply with mass balance requirements. In addition, cross section of a given pass may be obtained from the memorized values of edges location. Cross section of Pass #2, in Figure 7 may be obtained from edge location of second and third pass. Cumulative sections may well be computed too. This is useful in fillet welds where a cross section requirement for the weld exist and where most of the time, extra filler metal is added. By properly monitoring filler metal cross sections, major saving in unnecessary deposited metal may be achieved. The NRCC (IMRI) vision system makes it possible.

3.3.4 Other types of weld preparation. This system could be used to inspect the geometry of many other kinds of weld preparation like a fillet or a lap joint. In general, one should select an appropriate light pattern to be projected on the surface to be inspected and identify which singularities in the camera image should be tracked. The position in space of these singularities is then easily computed.

Using only the area and first moments measurements from each module, many singularities can be tracked. However, it would become possible to track more subtile singularities by using other measurements. Second moments for example are easily executed in real time and would be very useful as they would provide to the system additional information about the orientation and the eccentricity of the white level feature inside the window. We are now looking toward adding some of these new capabilities to our modules.

4. Conclusions

A new image processing algorithm for real-time adaptive arc welding was developed, using the rapid pre-processor initially developed as a visual aid for the space shuttle arm manipulation. The system was successfully used for real-time seam tracking, and for significant welding geometrical parameters measurements of butt, multipass and other types of welds. Significant geometrical welding parameters can be obtained and deposited filler metal monitoring can be achieved through relatively simple binary image analysis. The described schemes complement other approaches and have the advantages of achieving some of the welding adaptive functions at high speeds without too much technological sophistication.

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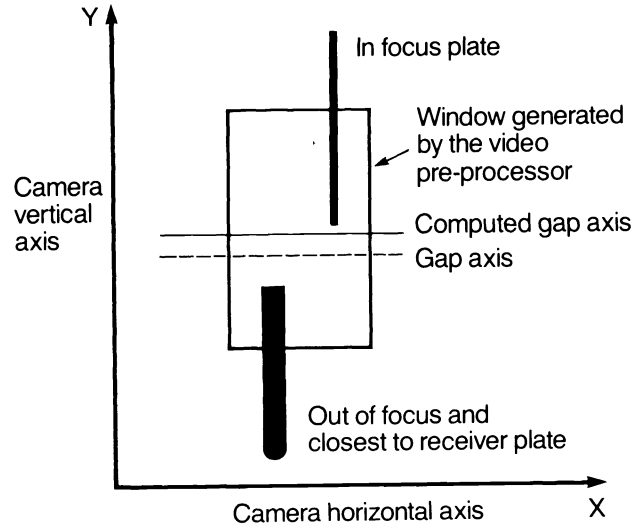
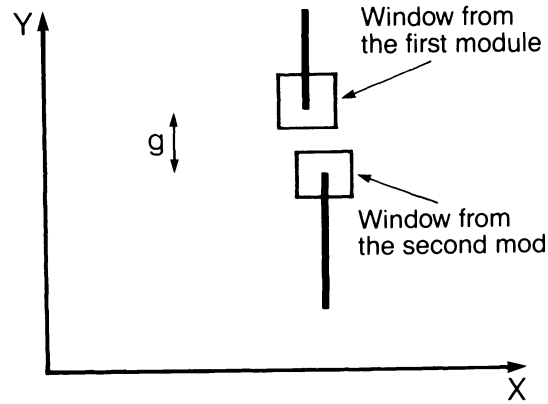


Figure 5 Error on the computed gap position caused by a large plate misalignment.



$g = Ko\ (Cy_1 - Cy_2)$

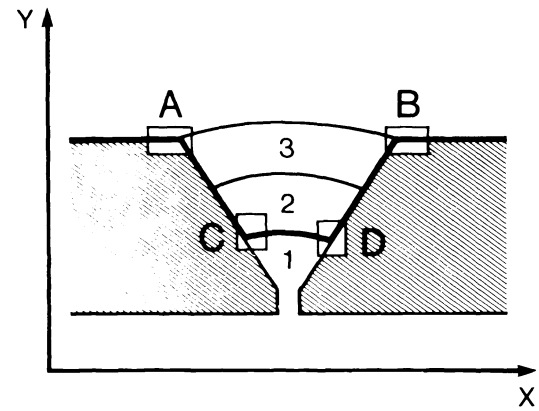
$p = K_1\ (Cy_1 + Cy_2)\ /\ 2$

$m = K_2\ (Cx_2 - Cx_1)$

where (Cx_1, Cy_1), (Cx_2, Cy_2) are surface centroid computed from the first and second module.

m is the misalignment.

Figure 6 Gap tracking for butt welding thin metal sheet with two modules.



The window tracking criteria is to maintain feature centroid at a specific region inside each window:

Window	Tracked position of the centroid
A	lower - left
B	lower - right
C	upper - right
D	upper - left

Also, each window should keep its approximate position relative to each other.

Figure 7 Multipass seam tracking. Window positions for the second pass are as shown.

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