A vision system for the automatic welding of thin stainless steel plates

Citation for published version (APA):
Huber, C., & Boderie, E. E. M. (1988). A vision system for the automatic welding of thin stainless steel plates. In *Advanced sensor technology : proceedings of the 7th international conference on robot vision and sensory controls, RoViSeC-7, 2-4 February 1988, Zuerich, Switzerland / Ed. W. Guttropf* (pp. 31-38). IFS.

Document status and date:
Published: 01/01/1988

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 01. Dec. 2020

Proc. Int. Conf. Robot Vision and Sensory Controls, 31-38
February 1988, © IFS (Conferences) Ltd and authors, ISBN 0-948507-780

A vision system for the automatic welding of thin stainless steel plates

C Huber and **E Boderie**
Eindhoven University of Technology, The Netherlands

ABSTRACT

The operation to be automated concerns the circumferential butt TIG-weld seam of cylindrical containers. The objective was to eliminate monotonous and eye-straining work, to ensure a more constant weld quality, and to achieve a higher productivity. Although the problem could have been solved by employing a conventional seam detection sensor, for various reasons preference was given to the use of a vision system. This paper describes the set-up and components used to obtain a suitable image in the presence of the arc and explains the method developed for extracting the control signal from the image in real time.

1 THE PROCESS TO BE AUTOMATED

The vision system to be described was designed for the Tungsten Inert Gas (TIG-)welding of circumferential seams of cylindrical stainless steel cans. The steel plate thickness is in the order of 0,8 ... 1,0 mm, whereas the can diameter is typically 300 ...500 mm. The joint to be welded is of the butt type consisting of the non-processed cut edges of the steel plates.

Fig. 1 shows the essentials of the original production set-up. We see the drum-like workpice rotated at a constant speed around its cylinder axis by a manipulator (not depicted) to which the parts to be joined are firmly clamped. A crossed pair of manual adjustment verniers carries the welding torch. Its tip has to be kept symmetrical to the joint and at a proper distance to the workpiece surface to ensure the desired weld quality.

The required tracking accuracy of the torch is about 0,5 mm. Dimensional tolerances of the workpiece, the clamp, and the placement of the workpiece on the clamp can cause the joint to swerve by that amount from its ideal path. This makes continual supervision of the process necessary in order to be able to make occasional torch position adjustments. In the original situation an operator would watch the welding arc through a dark glass and manually correct its position, when needed, by turning the appropriate vernier screw, while the workpiece is kept revolving at its pre-set constant speed.

Although, in due course, operators gain experience in judging just when to watch closely, when to relax, or even when to leave the process on its own for a time, this situation does give rise to occasional waste products that could be avoided by an automatic tracking system.

The aims in considering automation of this process can be summed up as follows:

(a) More efficient engagement of skilled personnel by
  - eliminating single-machine <u>operating</u> tasks and creating multiple-machine <u>supervision</u> tasks

(b) Improvement of working conditions by
  - eliminating monotonous work
  - eliminating unnatural and fatiguing visional stress

(c) Enhancement of production efficiency and product quality by
  - reducing waste production
  - achieving more consistent product quality through elimination of influence of varying human performance

Realization of these aims will have to result in a somewhat more cost-effective production to offset the investment in automation.

2 THE OPTIONS CONSIDERED FOR TRACKING CONTROL

Of the various possible solutions to the said automation problem, two exremes were chosen for comparison of their relative merits (fig. 2):

(a) A conventional, commercially available specialized seam detection sensor and an analogue servo loop

(b) A matrix camera based vision system with an image processor to generate the servo commands.

The attributes of the conventional system were not difficult to list, but to be able to compare it with the vision-based solution an investigation had to be carried out with respect to the latter to ascertain the

- feasibility of t.v.-type camera application
- type and volume of required software
- minimum hardware configuration
- expected start-up manpower investment

The main relative advantages of the conventional seam-tracking sensor option are:

- off-the-shelf commercially available

- turn-key installation by supplier
- minimum personnel training necessary
- requires little direct involvement of operators

The vision-based solutions's most prominent features were expected to be:

- visual contact of the operator with the welding process can be maintained and perhaps even improved
- human involvement with the production process is at a higher level of intelligence
- the system is software adaptable for other seam types

but at the cost of

- a high manpower investment to design and install the system
- greater capital investment to acquire the necessary hardware.

One of the results of our investigation was the surprising fact that the vision-based system's hardware cost would certainly not exceed that of the conventional sensor system.

3 THE PROPOSED SET-UP

The human eye and the dark viewing glass were to be replaced by an image sensor, a suitable near-infrared filter, and a monitor, while the manual adjustment was to be taken over by an image processor and a servo-drive for the y-control (see fig. 3), and an arc-voltage driven controller for the z-axis.

Our investigation goal did not require the actual execution of the servo-drives since they are of a well-known conventional nature once the extrication of the proper control signals from the sensors has been achieved. Neither did we believe that obtaining the z-signal from the arc voltage would prove difficult. So we concentrated on the image acquisition and processing problem.

4 IMAGE ACQUISITION

First of all it will have to be possible to capture some form of image of the seam and the torch in the presence of the arc. As with all arc-welding processes, TIG-welding is accompanied by an intense radiation which extends from the ultra-violet through to the infra-red. Since we wished to employ a low-cost vision sensor we were confined to using a commerically available industrial type video camera. Our choice fell on the HTH (High Technology Holland) MK1 CCD camera with an array of 604 x 575 pixels, which proved to be well suited for the job.

In selecting the appropriate radiation filter transmission wavelength interval, we were guided by the reasoning that the arc's least intense spectral region is towards the infra-red, while the workpiece would emit its most intense radiation in that same region. So, to bring contrast between workpiece and arc radiation into reasonable balance we thought it best to select a pass band near or inside the infra-red. The camera sensitivity region does not extend beyond about 1 µm, so that is where we chose the filter transmission.

Our experiments, however, revealed that the reflecting properties of the workpiece material, stainless steel, were such that the arc could be used as the light source, its mirror image in the workpiece surface clearly showing up the welding seam gap in front of the weld puddle. The arc also illuminates the torch sufficiently clearly to reveal its position against the somewhat darker background. Thus it appeared that no use needed to be made of the infra-red radiation of the workpiece, and hence that the transmission band of the filter was non-critical. A dark viewing glass, as usually used for manual welding, is sufficient. Fig. 4 gives the side view of the set-up.

The images we obtain are clear and meaningful, and viewable with much more ease than those directly viewed by looking at the process through protective glass. Also, by using a zoom lens, magnification can be adjusted to suit one's preference. In this way, even without automation of the arc adjustment, a camera and monitor is a worthwhile investment to ease the visual stress for the operator and to enable him, by choice of the magnification factor, to manually track the seam with enhanced accuracy.

Our experiments were run with a magnifiation factor that yielded a spacial resolution of 0,1 mm at the workpiece surface which is just about the width of a gap. But this is not neccessarily the optimum, nor is it a limit value. The intensity resolution was 16 grey levels. A typical image is to be seen on the photograph, fig. 5.

5 IMAGE PROCESSING

The images obtained reveal certain details which are schematically drawn in fig. 6.

To adjust the sideways position is a simple matter in principle: position the arc by aligning the symmetry axis of the torch with the centre of the seam gap. Thus, for the processing of the image it should be sufficient to process one line passing through a relevant portion of the torch and one line through the gap. This is what we essentially do (see fig. 7) and it makes real-time processing readily obtainable.

Locating the torch position poses no serious problems, but the line across the gap has to be selected carefully, because all kinds of interferences, such as the varying size of the arc, fumes, and varying optical properties of the gap and its vicinity, tend, at times, to obscure the gap or to contaminate the nominal intensity profile. So besides the selection of the proper line also a safe algorithm has to be developed to identify the gap within the intensity profile along this line.

The torch localising procedure is depicted in fig. 8. The intensity profile along the torch sensing line (TSL) essentially shows a well-defined pulse form. The grey level value of each pixel is stored in an array from where it can be taken to be processed. The first derivative (or differential) is obtained and also stored. Then, starting from the lowest pixel number, the array is scanned, each pixel value is checked against a threshold until the first beyond-the-threshold value appears and the corresponding pixel number p is stored. The same, but symmetric, process is repeated starting with the highest pixel number until the first beyond-the-threshold value is found at pixel number q. The torch centre is then assumed to be located at pixel number $\frac{1}{2}(p+q)$.

Essentially the same method could be used to find the gap position (fig. 9), were it not for the fact that the intensity profile can become very asymmetric with respect to the gap when the torch deviates from its proper path. Therefore the following safer procedure was devised (fig. 10):

(1) start left and store position of first local above-threshold maximum A
(2) repeat action, but start from right edge of image; this yields B
(3) search for absolute minimum between A and B; this yields C
(4) search for maximum negative derivative between A and C; that fixes the left edge of gap
(5) maximum positive derivative between B and C fixes the right edge of gap
(6) determine midpoint between the edges of gap which is assumed to be the centre of gap

To prevent both the torch and gap finding programmes to respond erroneously to incidental high interference peaks an extreme intensity and extreme derivative rejection procedure was incorporated. If a run fails to yield a conclusive position value the programme delivers "pixel number zero" as position data. This output value activates a misfire counting mechanism which produces the "end of seam" signal after a certain number of consecutive misfires have been detected.

6 THE TRACKING CONTROL SIGNAL

The difference between the position readings of torch and gap is to be used as the control loop signal to drive the vernier servoes. The known tolerances of workpiece, manipulator, and welding gear suggest that the torch, once it is precisely above the middle of the seam, could travel uncorrected for at least 4 sec. before accumulating too great a deviation. We were able to keep the processing time for a tracking control signal update below 100 ms. This means that the control data are available in real-time.

A number of safeguards are built into the programme, such as
- ignoring random higher level interference pixels
- bridging non-successful gap locating scans
- stopping the system when an above-tolerance gap deviation is encountered

The tracking procedure includes
- manual rough positioning of torch
- start-up phase with lenient safeguards
- tracking with stringent safeguards
- stopping at the end of the gap

7 THE DEVELOPMENT SYSTEM

To avoid having to set up actual welding apparatus in the laboratory, we compiled a videotheque of welding experiment recordings which contained all kinds of deviations from nominal operation as well as perfect runs. The reasoning behind this approach was that, if the software is able to derive the proper control signals from the recordings, it will surely be able to do that from direct camera inputs which have a better signal to noise ratio and tend to be more steady. Besides that, a video tape represents a reproducible experimental run, whereas the live situation is somewhat different all the time. This would make it difficult to check just exactly the influence of programme changes on the tracking performance.

The development hardware consisted of a frame grabber, an image memory, a computer and a monitor.

8 A DEMONSTRATION PROGRAMME

As stated in section 2, our investigation goal was not to come up with a complete system design but only to determine the feasibility of vision-based tracking control and to compare its cost with that of a conventional solution. To prove the effectiveness of the algorithm we therefore resorted to a demonstration of its ability to generate a control signal only, assuming that from there on it is merely a matter of applying known techniques to realize a total functional production unit.

The computer was programmed to insert a bright pixel into the live monitor image at both the calulated torch and gap position. In this way it could be clearly demonstrated that the positions are correctly calculated with a tolerance of ± 1 pixel (= ± 0,1 mm). This is well within the required tracking accuracy of ± 0,5 mm.

The tests also showed that the safeguards (see section 6) performed their tasks reliably.

9 HARDWARE REQUIREMENTS

Although the programme was developed on a system with a powerful computer it was borne in mind that one should be able to transfer it to a personal computer system without compromising with vital aspects such as the real-time requirement. The following hardware will be needed to do the job:

a CCD camera
a PC such as the IBM XT
a monochrome screen
2 floppy disc drives
MS-DOS
a frame grabber and memory cards (e.g. Imaging Technol. Inc. PC-Vision PFG-8-1-E-XT)
I/O facilities (e.g. Burr Brown PCI-20.000 series)
turbo-Pascal software
standard type monitor
2 servo drive amplifiers and servo verniers

10 CONCLUSIONS

The investigation shows that vision-based seam tracking is possible using a personal computer system. A CCD camera with a dark glass filter yields usable images, but the two sensing lines have to be chosen judiciously to achieve reliable position data. Processing time can be kept below 100 ms which is sufficiently short to be called real-time for this welding operation.

In contrast with a conventional seam tracking sensor, the vision sensor allows the operator to visually monitor the process on a screen and with variable magnification. The vision system, employing a personal computer, need not be more expensive to buy than a conventional tracking sensor system, but the man-power investment to start it up will be considerably more than that for the conventional solution. However, once the owner company has built up the expertise, the vision system will be more agreeable to work with and more flexible with respect to different forms of seams and/or workpiece geometry.

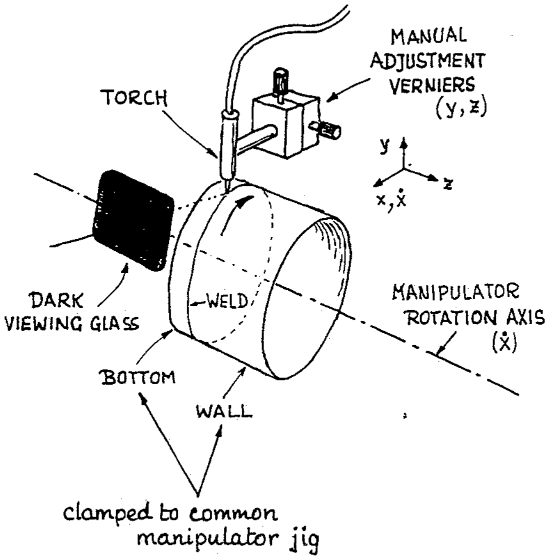


FIG. 1 The original production set-up

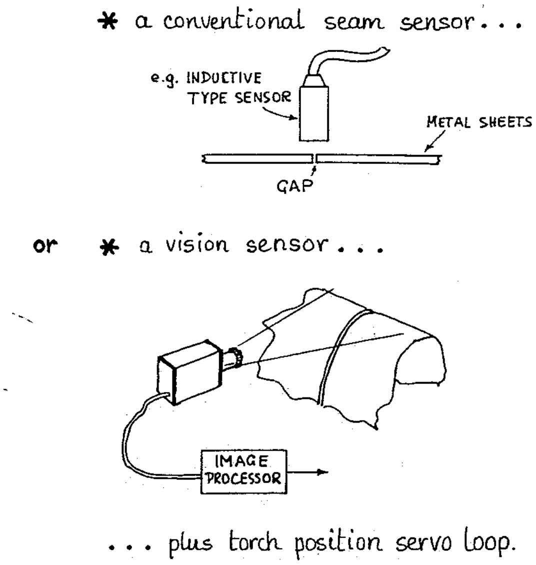


FIG. 2 The options compared

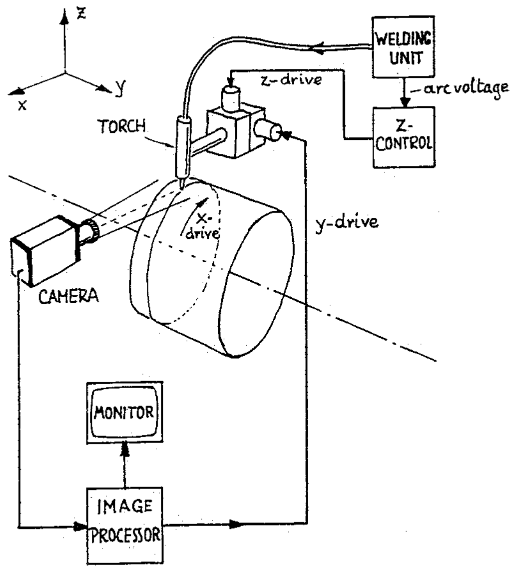


FIG. 3 The vision guidance set-up

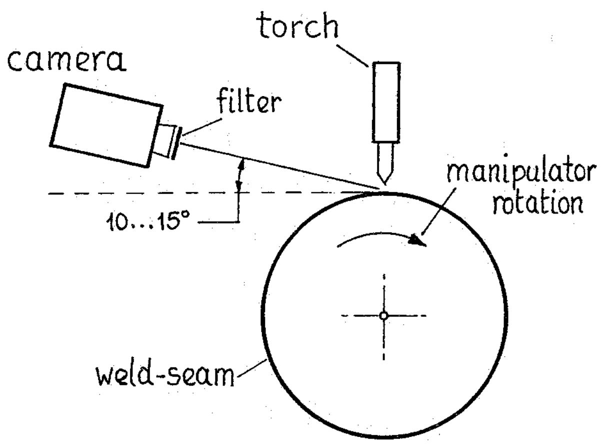


FIG. 4 The optimum camera position

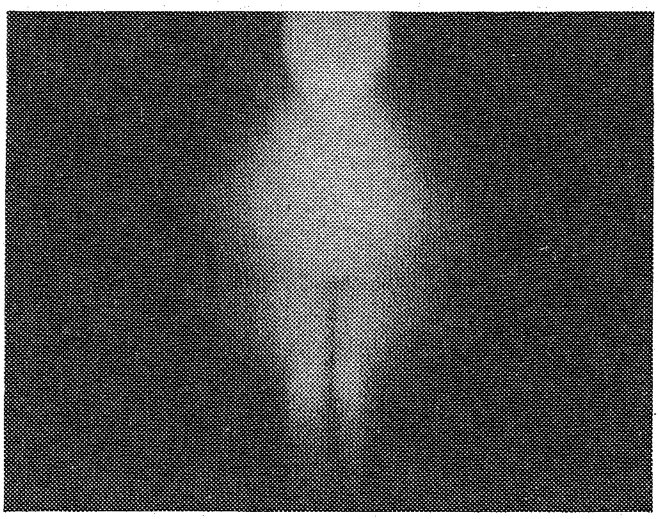


FIG. 5 Typical monitor image of the welding process

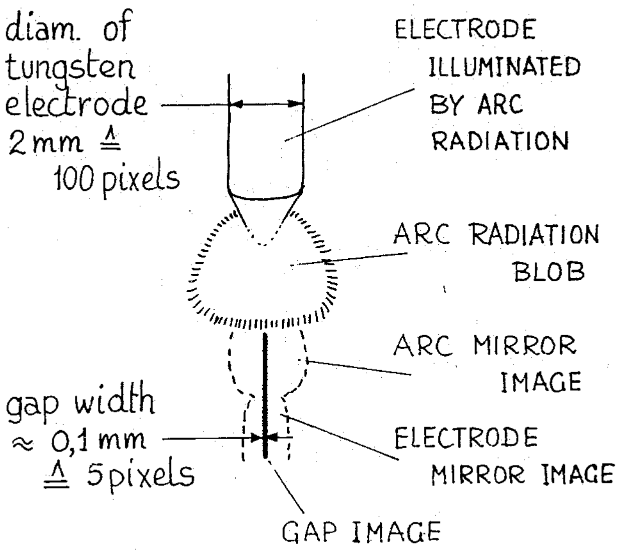
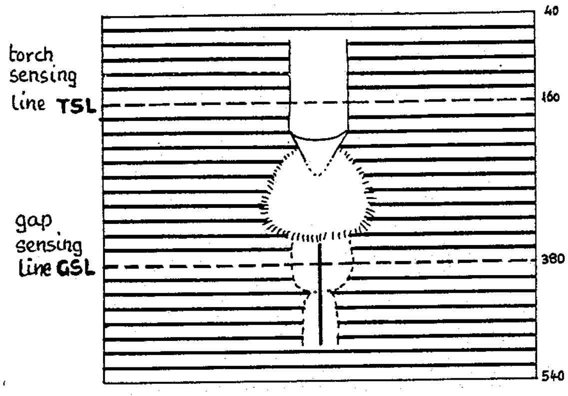


FIG. 6 Typical image composition



TSL: non critical
GSL: optimum line number to be determined empirically

FIG. 7 Selection of sensing lines

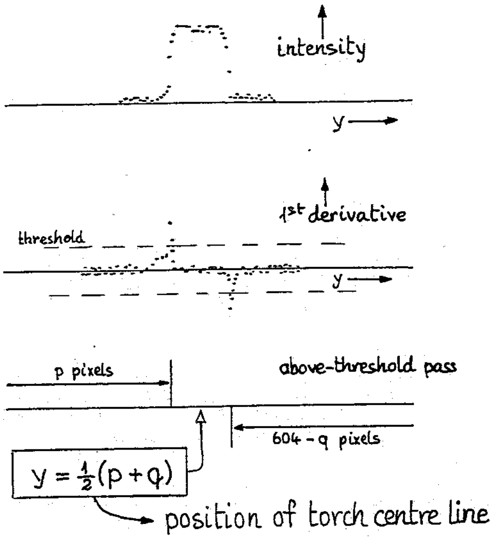


FIG. 8 Determining the torch centre line

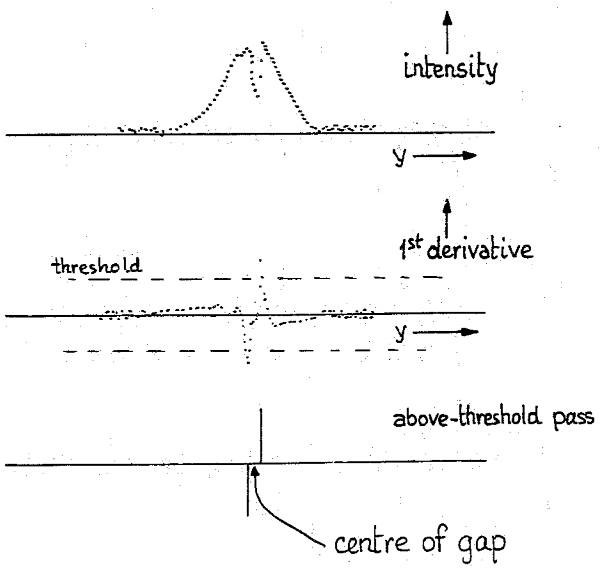


FIG. 9 Gap detection with correct tracking situation

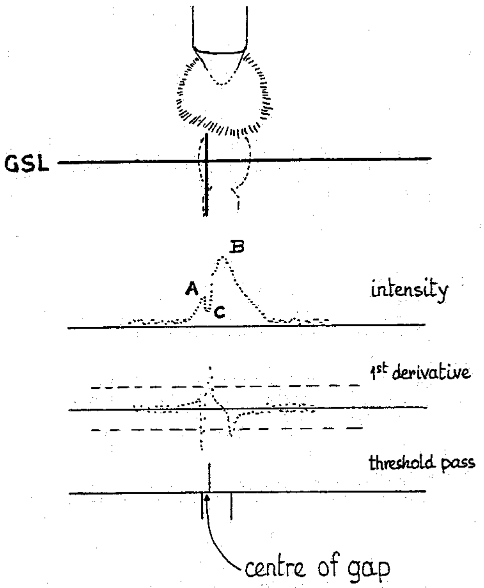


FIG. 10 Gap detection with asymmetric track